BY E. M. KHALIMOV, ET AL.

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COMPREHENSIVE STUDY OF THE GEOLOGICAL STRUCTURE OF MULTIRESERVOIR OIL DEPOSITS

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[Excerpt] Chapter 2. Zonation and Correlation of Producing Sections

The Zonation and Correlation of Sections of Terrigenous Deposits from Core and Geophysical Field Data

The zonation and correlation of well profiles are among the most urgent problems being solved by methods of oil field geology. On the precision of reservoir correlation will depend the scientific selection of objects to be operated and the rational system of working the pools.

In the direct study of continuous core columns the correlation of any complex geological section is facilitated somewhat. Determination of the micro- and macrofauna and of the mineralogical composition, granulometric analysis, the study of clay minerals, etc, are possible in that case. But most often the oil field geologist has available only a very small number of cores or no cores at all. In such cases geological materials acquire a decisive role in correlation.

As is known, sections of terrigenous producing formations of such large deposits as the Tuymazinskoye, Romashkinskoye, etc, were zoned with the use of general methods. But the zonation of the terrigenous formation of the Lower Carboniferous period of Bashkiriya, as well as of other oil-bearing rayons of Volgo-Ural'skaya Oblast, by means of widely used methods is an extremely complicated matter. The difficulty of the given problem is explained by the fact that the formation has very sharp variations of thickness (from 0 to 200 m), different stratigraphic volumes, different lithological composition, a sharply expressed lithological variability of close sections, etc.

Thus, for the territory of Bashkiriya, for example, at the present time there are up to 10 different types of terrigenous sections. With the generally adopted method of correlating deposits only on the basis of sandy-siltstone rocks the goal is not always achieved, since those sediments, in view of their single-mineral (quartz) composition and their being well sorted out, look very uniform in any part of the section and often taper out in a short distance. As a result of that correlation the zonation of some of the same sections by different researchers looks different [27,28].

To correlate terrigenous sections of Lower Carboniferous deposits we have compared the bands of argillites and and strongly clayey siltstones that separate producing reservoirs [5,38]. Those bands are traced with great constancy in the deposits under consideration and, as is very important for oil field practice, are depicted well on diagrams of the geophysical comples and especially distinctly on cavernograms. In addition, due to their disperseness, clayey rocks have a large variety of properties and features characteristic of rocks of a source area and a sedimentation base are preserved better in them, and even when thicknesses are small they persist more along the strike within certain regions. An example of the use of such a method of correlation in studying the multireservoir Arlanskoye deposit is described below (Figure 1).

In that region, to substantiate certain logging data, a complete lithological mineralogical study was made of the argillites in sections in which the core removal was fairly high (80-90 percent). A very varied and complete group of physical methods of investigation was used to characterize the argillites. Besides detailed macro- and microdescription of the samples, chemical, X-ray structure (diffractometric and Debye methods), spectrum and other analyses were carried out. Detailed analysis of the mineralogical composition of the argillites and clayey siltstones, and also consideration of the accompanying non-clayey minerals and the character and quantity of the fauna permitted breaking down the section of the terrigenous formation into a series of alternating bands of clayey rocks and producing reservoirs. The characteristics of the argillites were established: the predominant mineral composition and textural, structural and other specific features.

In accordance with the predominance of given clay minerals in sections of the terrigenous formation of the Lower Carboniferous period of the platform part of Bashkiriya, different types of clayey rocks (argillites and clayey siltstones) are distinguished. The most widespread, both over the section and over the area, are rocks with hydromicaceous association; kaolinitic rocks are traced in a narrow interval of the section. Such a confinement of various clayey rocks to individual parts of the section permitted distinguishing several mineralogical zones, tracing them on the studied territory and comparing sections both within an individual area and between different regions.

The terrigenous formation of the Lower Carboniferous of northwestern Bashkiriya is included between the carbonate deposits of the Turneyskiy stage and the Tul'skiy horizon and embraces the Yelkhovskiy, Radayevskiy, Bobrikovskiy and Tul'skiy horizons.

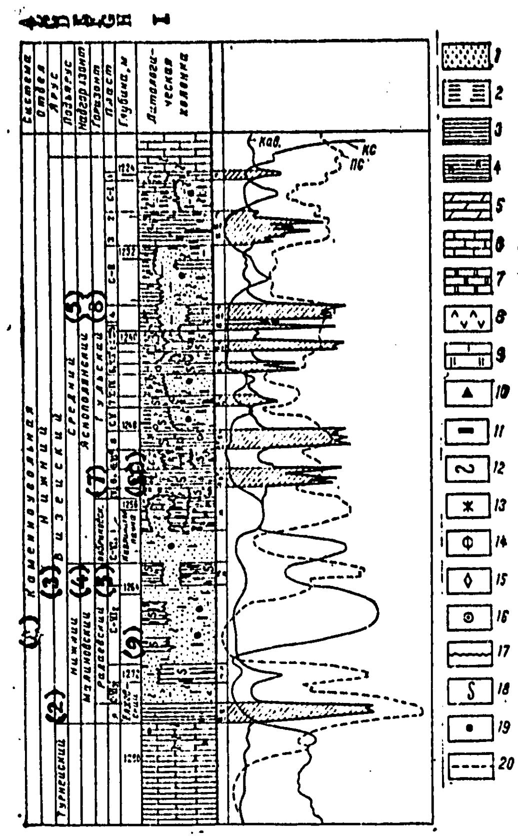


Figure 1. Summary lithological-geophysical section of a terrigenous formation of the Lower Carboniferous period of the Arlanskoye oil deposit

1 -- sandstone
2 -- siltstones
3 -- argillites
4 -- light-gray kaolinitic argillite
5 -- marl
6 -- limestones
7 -- dolomites
8 -- anhydrites, gypsums
9 -- calcareous, dolomitization
10 -- silicification
11 -- coals
12 -- siderite
13 -- iron oxides
14 -- phosphorite
15 -- zeolite
16 -- oolitic formations
17 -- rock erosion
18 -- rocks with crumpled texture
19 -- industrial oil content
20 -- position of water-oil contact
K -- kaolinite
M -- montmorillonite
Г -- hydromica
Г-М -- mixed layered mineral of the type of montmorillonite-hydromica

A -- system
B -- series
C -- stage
D -- substage
E -- suprahorizon
F -- horizon
G -- bed
H -- depth, m
I - lithological column

The Yelkhovskiy horizon is formed of argillites and strongly clayey, often limestone silts. The mineralogical composition of the argillites and clayey cement of silts is mainly hydromicaceous, rarely montmorillonite-hydromicaceous. The argillites are clearly depicted by increase of amplitude of the cavernogram, and also on the SP and GM [expansions unknown] curves. The thickness of the Yelkhovskiy horizon varies from 1 to 5 m.

The sediments of the Radayevskiy horizon (a siderite-kaolinite-hydromicaceous zone) are distributed over the entire territory of platform Bashkiriya. The sandstones and siltstones of sections of that horizon are gray, more rarely dark-gray, quartz, well sorted out, at times clayey, and calcareous. The argillites of the horizon are of dark-gray color, finely dispersed or silty, micaceous and sideritized. The argillites and clayey siltstones are composed of a kaolinite-hydromicaceous association. The quantitative kaolinite-hydromica ratios are very varied over both the section and the area. The presence of siderite, the kaolinite-hydromica composition, the clayeyness and great density and unwettability of the rocks are characteristic features of dense sections within producing reservoir C-VI.

The sediments of the Bobrikovskiy horizon (a kaolinitic zone) consist mainly of a sandy or siltstone reservoir and a kaolinitic band covering it. The sandstones of the Bobrikovskiy horizon are of gray and light-gray color and are quartzous. The siltstones are more often distributed in sections with a small thickness of the Bobrikovskiy horizon. They are of gray and dark-gray color, are quartzous, and are clayey and carbonaceous.

In the roof of the horizon of most sections of the main deposits a band of light-gray kaolinitic argillites, very dense, strong, of the type of "kremnevkas" (kaolinic refractory clay) or other kaolinic clay, is traced. The argillites are not wetted in water, are clearly distinguished by their light coloration from the entire section and are a marking interstratification of the roof of the Bobrikovskiy horizon (a kaolinitic band).

Characteristic of some sections is the presence not only of light-gray but also of reddish and greenish kaolinitic argillites. Light-gray differences of argillites often change along the strike into carbonaceous-clayey rocks or into clayey siltstones and sandstones with frequent light-gray selvedges; in the latter case the Bobrikovskiy horizon consists only of sandstones and siltstones.

The log characteristics of light-gray kaolinitic argillites and the carbonaceous-argillitic rocks underlying them are similar: corresponding to them are positive values on the PS curve, the increase of the values of the apparent resistance and the usually steady cavernogram. The thickness of sediments of the Bobrikovskiy horizon is very small (5-15 m).

Connected with the sandy-siltstone rocks of the Radayevskiy and Bobrikovskiy horizons are the oil deposits not only of Bashkiriya but also of Kuybyshevskaya and Permskaya oblasts and Tatariya.

The deposits of the Tul'skiy horizon (the upper hydromicaceous zone) consist of terrigenous and carbonate-terrigenous complexes of rocks, as well as of carbonate formations. In the northern part of Bashkiriya the Tul'skiy horizon is almost completely composed of sandstones and siltstones, and the limestones and marls form single thin layers. The horizon thickness varies from 25 to 50 m. The sandstones of the Tul'skiy horizon are light and dark gray in color, depending on their content of coaly-clayey material; the quartzous, with rare grains of feldspars, are fine-grained and silty to a different degree, at times with an admixture of medium-sized grains. The thickness of the layers of sandstones varies from zero to 14 m, but more often is 1 or 2 m.

Up to eight sandy-siltstone producing reservoirs are encountered in the sction of the Tul'skiy horizon of northwestern Bashkiriya (Figure 1). Sections are noted in which all eight producing reservoirs consist simultaneously of rock traps and sections with the presence of one or two layers (Figures 1 and 2).

An association of clay minerals together with non-clay minerals, and also the presence of individual groups of fauna and flora, permitted distinguishing a number of clay layers in the section of the Tul'skiy horizon. Those layers have correlation importance and are traced with the main deposits of northern Bashkiriya.

At the base of the Tul'skiy horizon lie two layers of argillites (8 and 8_1), well expressed by anomalies of approximately equal amplitude on the cavernogram curve, which reflects increase of the borehole diameter (Figures 1, 3 and 4). Layers 8 and 8_1 are composed of argillites that are wetted well in water, with frequent gliding planes and a shell-like cleavage, at times lumpy. Very characteristic of those layers is fine elutriation of clayey material, the presence of siderite, rare oolitic formations of hydrobiotite, rare fragments and segregations of phosphorite and individual tests of pelecypods and brachiopods (Figure 5b, c). The mineralogical composition of the argillites is hydromicaceous, at times with an admixture of montmorillonite. The thickness of the argillite layers varies from zero to 4 to 5 m.

Between the layers of argillites 8 and 8_1 lies producing reservoir C-VI^0, with a thickness of 0.8 to 5 m. Above layer 8 is sandy-siltstone reservoir C-V, covered with artillites or clayey siltstones of layer 7.

Layer 7 separates reservoirs C-V and C-IV. It is composed mainly of coaly-clayey siltstones and argillites. Characteristic of the layer are elutriation of the clayey material, a considerable content of coal and mica, the presence of frequent centimeter exfoliations of coaly-clayey siltstone with a mainly hydromicaceous composition, the presence of nodules of siderite and iron oxides and the frequent presence of oolitic formations of hydrobiotite. In some layers all those characteristics can be found, but in most cases only one of them is observed. The layer thickness

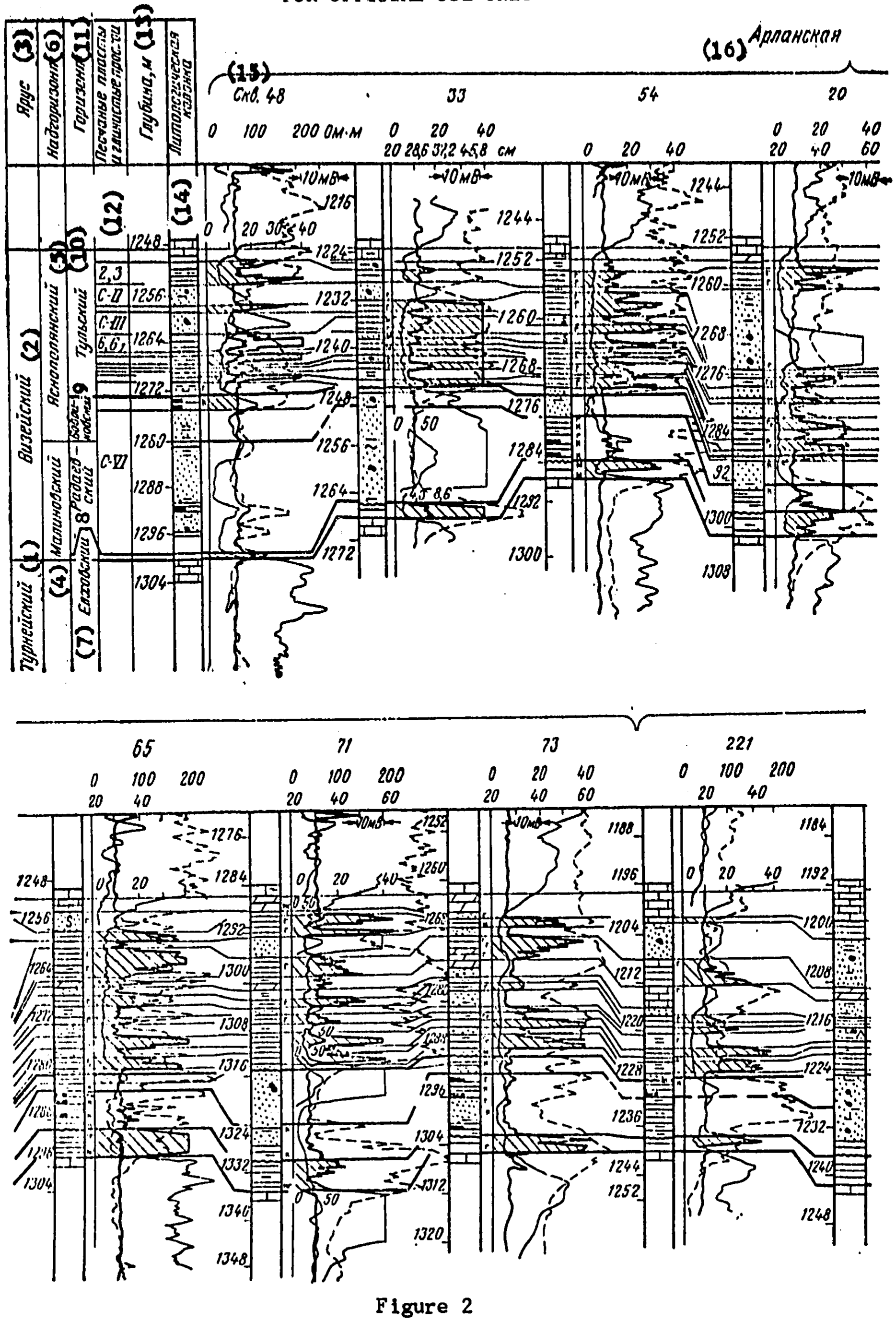


Figure 2

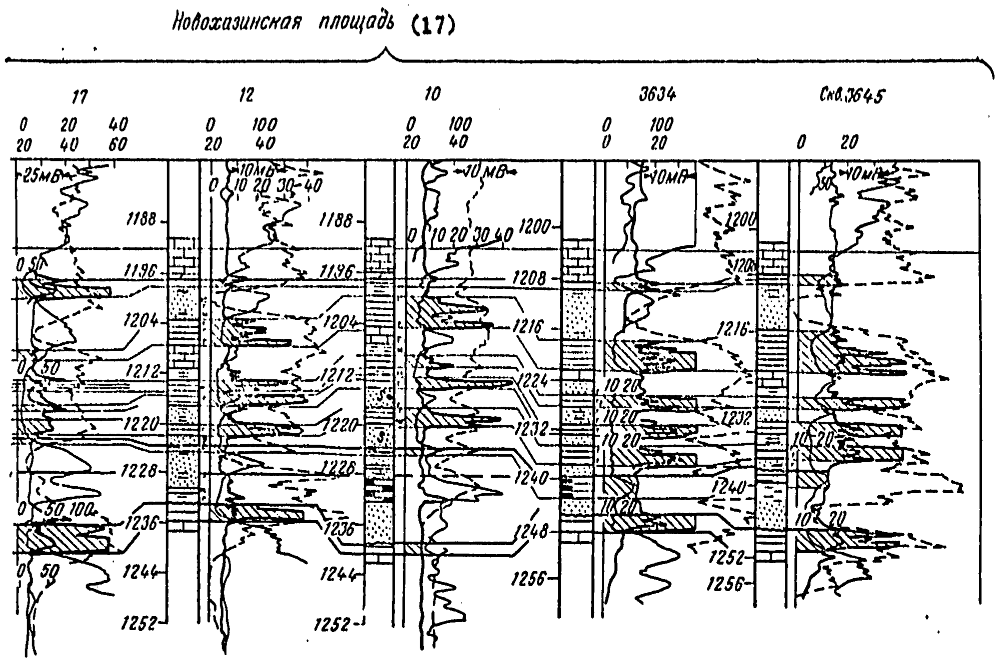


Figure 2. Schematic comparison of well sections of the Arlanskoye oil deposit. om = Ohm mB = mV

1 -- Turneyskiy
2 -- Vizeyskiy
3 -- stage
4 -- Malinovskiy
5 -- Yasnopolyanskiy
6 -- Suprahorizon
7 -- Yelkhovskiy
8 -- Radayevskiy
9 -- Bobrikovskiy
10 -- Tul'skiy
11 -- Horizon
12 -- Sandy reservoirs & coaly layers
13 -- Depth, m
14 -- Lithological column
15 -- Well (48)
16 -- Arlanskaya area
17 -- Novokhazinskaya area

is not great, from zero to 3 m. With increase of thickness that layer is usually broken down into several layers of argillite and clayey siltstone (Figure 4). Clayey layer 7 is expressed on the cavernogram by two peaks of a slight anomaly.

Above bed C-IV lie carbonate-clayey rocks, among which two clayey reservoirs are distinguished (6 and 6_1) with a thickness of 1 or 2 m, which separate producing reservoirs C-IV, C-IV^0 and C-III.

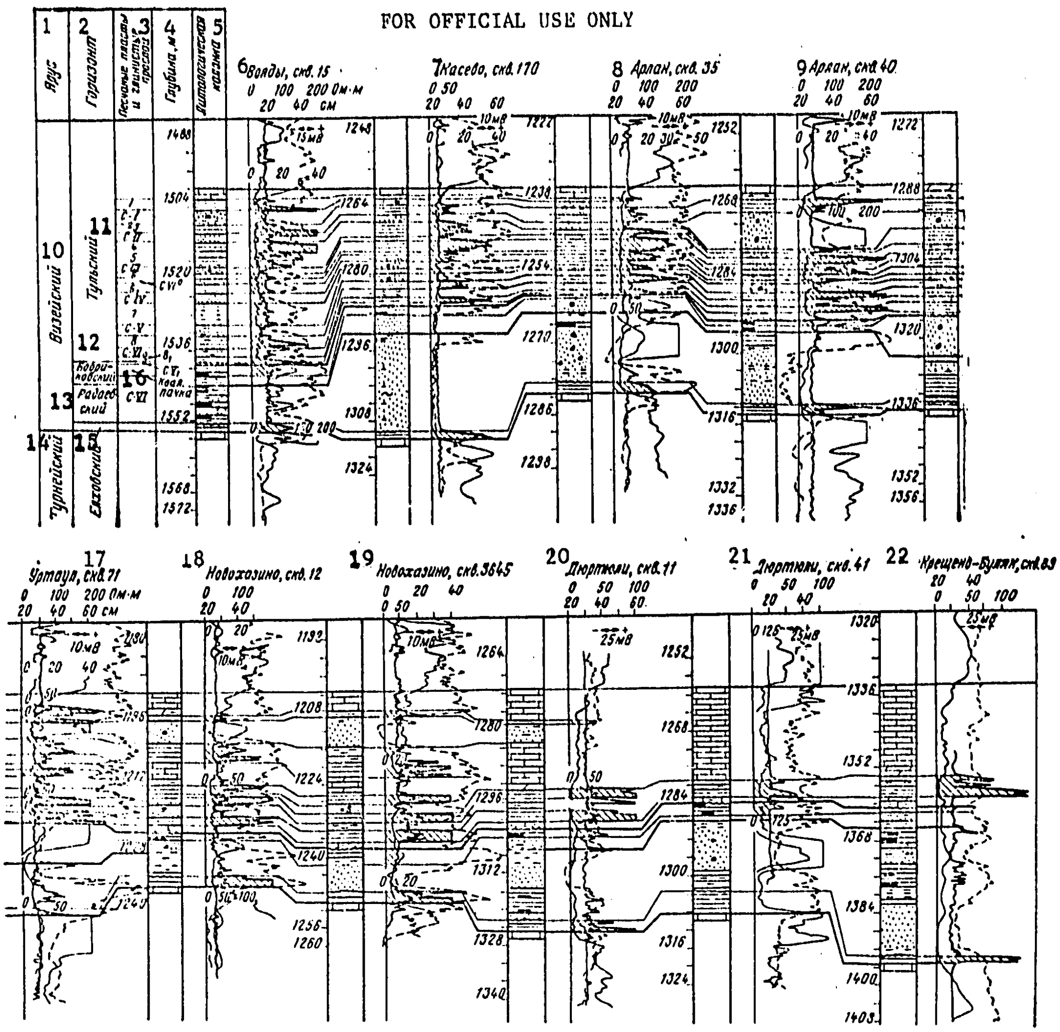


Figure 3. Schematic comparison of profiles of the terrigenous formation of the Lower Carboniferous along the line Voyady-Kreshcheno-Bulyak.. om = ohm mB = mV

1 -- Stage
2 -- Horizon
3 -- Sandy reservoirs & clayey layers
4 -- Depth, m
5 -- Lithological column
6 -- Voyady, well 15
7 -- Kasebo, well 18
8 -- Arlan, well 35
9 -- Arlan, well 40
10 -- Vizeyskiy
11 -- Tul'skiy
12 -- Bobrikovskiy
13 -- Radayevskiy
14 -- Turneyskiy
15 -- Yelkhovskiy
16 -- Kaolinite band
17 -- Cheraul, well 71
18 -- Novokhazino, well 12
19 -- Novokhazino, well 3645
20 -- Dyurtyuli, well 11
21 -- Dyurtyuli, well 41
22 -- Kreshcheno-Bulyak, well 89

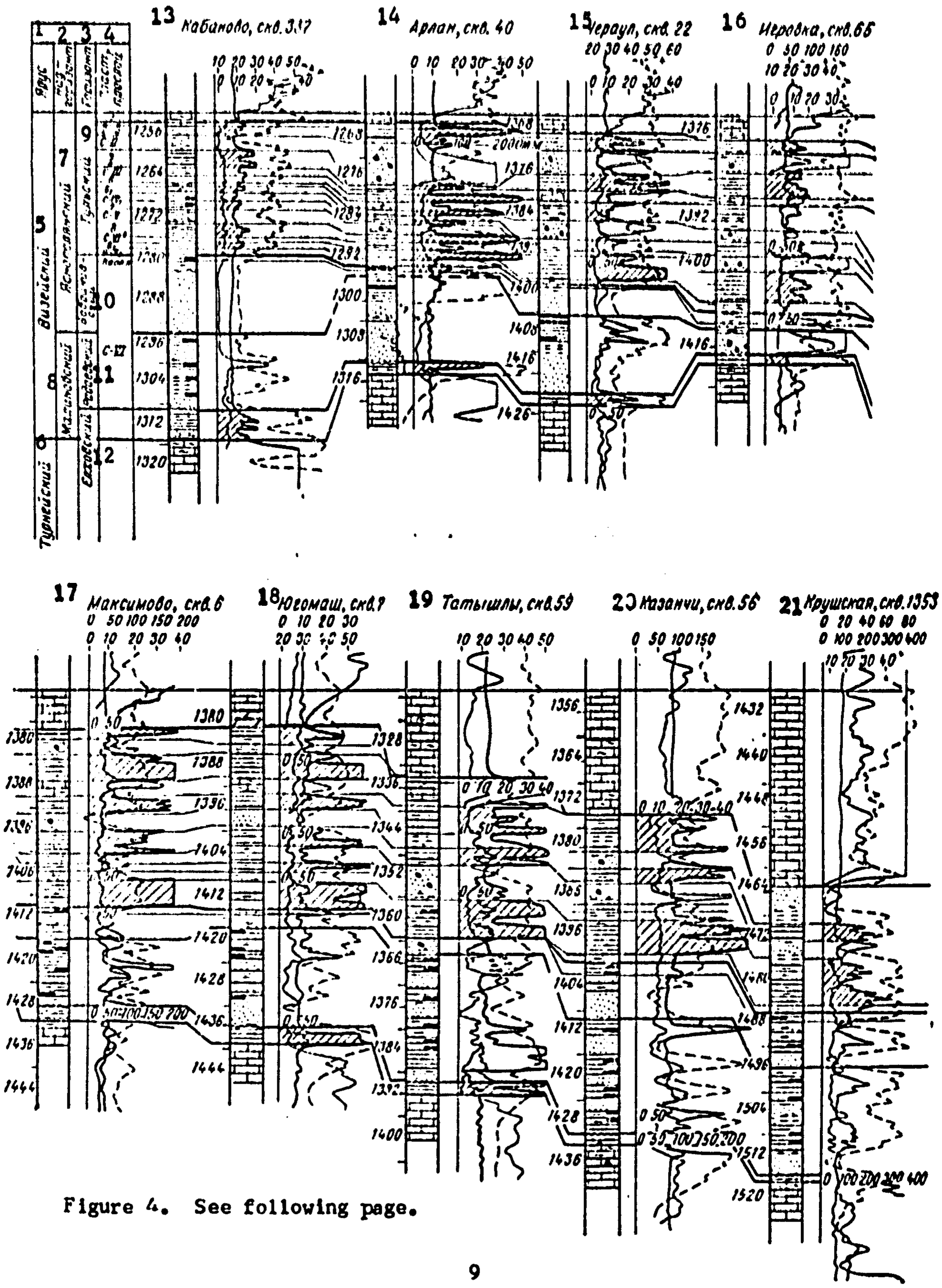


Figure 4. See following page.

Figure 4. Schematic comparison of sections of the terrigenous formation of the Lower Carboniferous along the Kabanovo-Krushakaya line of wells.

1 -- stage
2 -- suprahorizon
3 -- horizon
4 -- bed, layer
5 -- Vizeyskiy
6 -- Turneyskiy
7 -- Yasnopolyanskiy
8 -- Malinovskiy
9 -- Tul'skiy
10 -- Bobrikovskiy
11 -- Radayevskiy
12 -- Yelkhovskiy
13 -- Kabanovo, well 337
14 -- Arlan, well 40
15 -- Cheraul, well 22
16 -- Igrovka, well 65
17 -- Maksimovo, well 6
18 -- Yugomash, well 7
19 -- Tamyshly, well 59
20 -- Kazanchi, well 56
21 -- Krushskaya, well 1353

Layers 6 and 6_1 are composed of argillites which are wetted well in water, with shell-like cleavage and gliding planes. Characteristic of the layers are both disperse and silty varieties of argillites, mainly a hydromicaceous composition with admixture of montmorillonite, the calcareousness of the rocks, the presence of algae residues and fragments of the tests of brachiopods and the presence of individual segregations and fragments of phosphorite.

The strongly clayey and calcareous differences of the siltstones of reservoirs C-IV^0 and C-III often contain fragments of the calcareous tests of the ostracods and brachiopods, lens-shaped inclusions of limestone and fragments of calcareous algae. South of the Arlanskaya area there is a gradual replacement of bed C-III and the argillite layer underlying it, and further south in that part of the section is developed clayey limestone with a thickness of 4-5 m that is well depicted on the logging diagrams and is a reliable reference point (Figures 2 and 3). East of the Arlanskaya area a replacement of terrigenous rocks by carbonates also is manifested and a marking reservoir clayey limestone appears (Figure 4).

Layer 5 of clay rocks has a total thickness of about 0.5 m, but its lithological and mineralogical features and its position in the section are very stable. The argillites of the layer are of dark-gray color, are well wetted in water, are filled with residues of calcareous algae, and often by fragments of brachiopods and segments of crinoids. The mineralogical composition of the clayey substance is hydromicaceous and montmorillonitic.

Layer 4 of argillites with a thickness of 3-4 m is traced higher. The argillites are micaceous and silty, and horizontally layered. Finely disperse varieties of argillites with gliding planes and shell-like cleavage are well wetted in water. The mineralogical composition of the argillites is hydromicaceous and montmorillonitic-hydromicaceous. Encountered all over the interbed are large nodules of pyrite which reach 2-3 cm in diameter, pyriticized fragments of the tests of brachiopods and pelecypods, and also pyriticized remains of plants (Figure 5d, e, f).

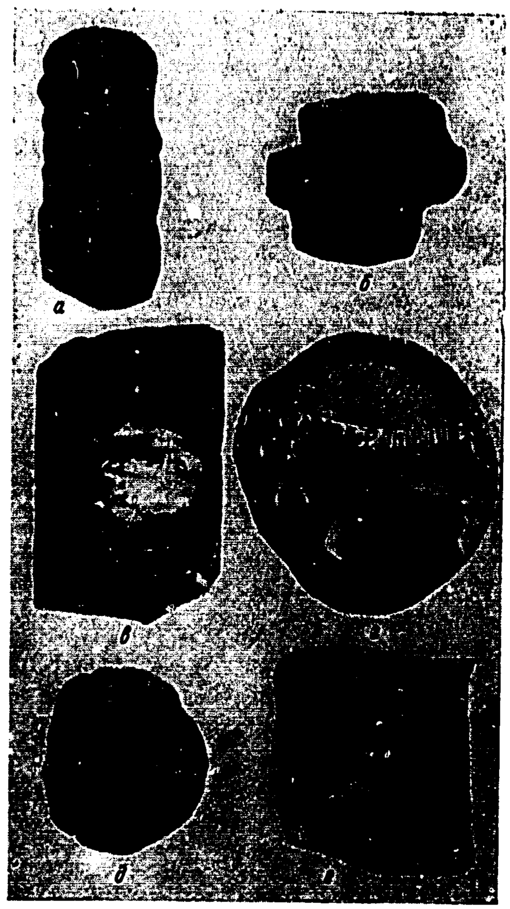


Figure 5. Core samples. a - dark-gray argillite with shell-like and foliaceous cleavage. the Yelkhovskiy horizon (Teplyaki, well 32, 1481-1484 m interval); b - dark-gray argillite with siderite exfoliation. Layer 8 (Arlan, well 289, 1214.8-1219.8 m interval); c - dark-gray argillite with phosphorite nodule. Layer 8 (Arlan, well 293, 1222.7-1231.4 m interval); d - argillite with fragment of fauna. Layer 4 (Arlan,

well 287, 1208-1213 m interval); e - argillite with residue of calcareous algae. Layer 4 (Arlan, well 75, 1218.0-1221.8 m interval); f - argillite with pebble of phosphorite rock. Layer 4 (Arlan, well 293, 1213-1218-m interval).

Traced above layer 4 of argillite is the main productive reservoir of the Tul'skiy horizon C-II, above which an argillite-siltstone layer is distinguished (marks 3 and 2). Layers 3 and 2 are distributed mainly in sections of the Arlanskoye deposit (Figures 2 and 6). Characteristic of them is poor wetting of the clay material, hydromicaceous and montmorillonite-hydromicaceous composition, calcareousness and lens-shaped inclusions of calcareous siltstone. The total thickness of the layers 1 to 3 m.

Producing reservoir C-1 is covered by a layer of argillite 1 consisting of calcareous argillites or irregularly by siltstone marls. The rocks are of dark-gray color; the clayey matter in them is of hydromicaceous composition. They are filled with organogenic fragmentary material, poorly preserved. The layer thickness is about 1 m.

The section of the Tul'skiy horizon ends in limestones, the thickness of which increases in southern and eastern directions from the Arlan deposit.

Thus the section of the terrigenous formation of the Lower Carboniferous is characterized by a cyclic alternation of clayey sediments with sandy-siltstone formations. Whereas the distinguishing of each variety of rocks on logging diagrams presents no special difficulty, determination of their stratigraphic classification and places in the section is very difficult.

Those sections have also been correlated by computer [11]. The reference marks separating the reservoirs were characterized by a complex of oil field geological data: PS [expansion unknown], KS [resistance method], GM [gamma-method], NGM [neutron gamma-method], MGZ, MPZ [expansions unknown] and the cavernogram. In addition, geometric characteristics were also used: the thickness of the reference mark and the ratio of the distance from the roof of the reference mark to the band thickness. Eleven parameters were processed in all.

The correlation of sections is reduced to the task of recognizing five classes of reference marks R_i. To process the functions of the distance $\rho(P, R_i)$ from the arbitrary example P to the class R_i, $i = 1, \ldots, 5$, the function of the distances between the examples P and M is found in the form:

$$\rho_i(P, M) = \sum_{k=1}^{11} \alpha_k^i \varphi_k(P, M). \qquad (1)$$

The coefficients α_h are so selected that the ratio of the diameter of the class R_i (in the 11-dimensional space of those parameters) to the distance from that class to the combined remaining classes was minimal. After that

$$\rho(P, R_l) = M \xi R_l \min \rho_l (P, M).$$

Taken as $\phi_h(P, M)$ is the square of the difference between the values of the k-th parameters of examples P and M.

The question of the reference mark to which a recognized example belongs is solved on the basis of the values of the integral distances

$$r(P, R_l) = \sqrt{\sum_{l=1}^{5} \left(\frac{\rho_l(P) - \bar{\rho}_{il}}{\sigma_{il}} \right)^2}, \qquad (2)$$

where $\rho_{ij}(\sigma_{ij})$ is the arithmetic mean (mean-square) deviation of the distances of the training examples of the class R_i to R_j. That is, the example is related to the one of the reference marks R_i to which the distance from it is minimal.

The training was done on materials relating to the Cheraul area, for which 18 objects were selected for the class C_1, 18 for C_2, 19 for C_3, 18 for C_4 and 16 for C_6 at n = 11 and m = 5; $\phi_h(P, M)$ is the square of the difference between the values of the 11-th parameter of the objects P and M. The identical number of objects is if possible placed in the standard and test groups of each class. Used for recognition was a combination of schemes I and III from [11], that is, in each of the worked wells P the distance $r(P, C_1)$ from which to the class correlated (for example, the i-th) is the least. If $r(P, C_1) \leq 2.5\sigma_{11}$, the argillite P is placed in class C_1; for $2.5\sigma_{11} < r(P, C_1) \leq 4\sigma_{11}$ the reference mark was considered to be unrecognized; for $r(P, C_1) > 4\sigma_{11}$ absence of the corresponding reference mark in the well was established.

Four wells of the Charaul deposit were selected in which all the reference marks were present and correctly recognized. Then without additional training the sections of four wells of the Novokhazin area were correlated on which those reference marks are also traced. The result of the recognition was as follows: the reference marks R_1, R_4 and R_5 were recognized correctly, R_6 was recognized in all wells except one, where it was considered absent, which corresponds to reality, since in that well it was replaced almost completely by siltstones. In two cases reference mark R_2 was recognized incorrectly; this indicates a need for additional training in the transition to a new deposit. In well 5 the absence of R_4 was correctly determined and for the argillite nearest (in distance) to R_4 the deviation of the distance from the mean exceeded $6\sigma_{44}$ (Figure 7).

Because the parameters of the reference marks vary from area to area and new reference marks appear, the training material must be automatically renewed.

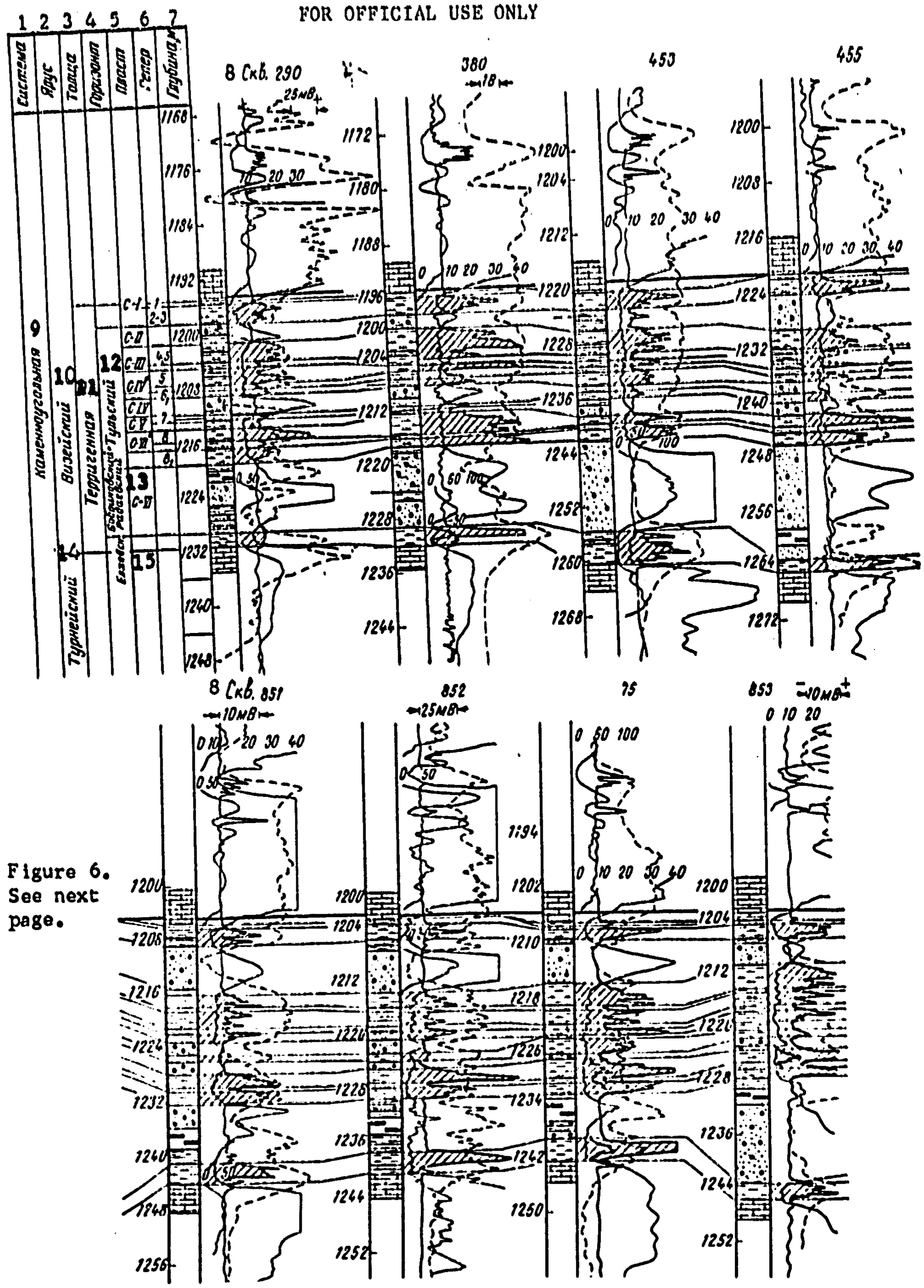


Figure 6. See next page.

Figure 6. Schematic comparison of sections of the Arlan deposit.
mB = mV

1 -- system
2 -- stage
3 -- formation
4 -- horizon
5 -- reservoir
6 -- reference mark
7 -- depth, m
8 -- well
9 -- Carboniferous
10 -- Vizeyskiy
11 -- terrigenous
12 -- Tul'skiy
13 -- Bobrikovskiy & Radayevskiy
14 -- Turneyskiy
15 -- Yelkhovskiy

Let us note that the drawing in of parameters characterizing the mineralogical composition of the reference marks being correlated evidently will permit improving the results of recognition and get rid of undesirable geometric characteristics.

It is advisable to use the proposed method in an automated system for processing field geophysical data, including the preliminary distinguishing of reservoirs over a section and the automatic taking of their mean characteristics with available algorithms. Those data will permit further processing of the geological materials by computer.

Method of Zonation and Correlation of Carbonate Deposits by Computer

In the zonation and correlation of carbonate deposits it is important to establish general regularities in the structure of the rocks. On how correctly they have been established will depend the precision of the correlation of the well sections by layers. The investigator must strive to use all the available geological-geophysical and field material and in mass processing draw in mathematical methods and the computer.

Study of the structure of carbonate deposits, determination of the correlation characteristics and comparison of producing reservoirs are examined on the example of the carbonate deposits of northwestern Bashkiriya. A section of the Middle Carboniferous, represented by the Bashkirskiy and Moskovskiy stages, consists of carbonate formations of various types with subordinate layers of terrigenous sediments.

With geological and oil field geophysical data in the interval of the section from the upper part of the Bashkirskiy stage to the roof of the Podol'skiy horizon on the territory of northwestern Bashkiriya 11 recurrent two-term complexes of carbonate rocks (rhythmically constructed bands I-XI) are distinguished (Figure 8). The lower part of each of the bands is represented by a very pure variety of carbonate rocks, as a rule containing porous-permeable varieties (the "productive" reservoir), and the upper by denser clayey-carbonate rocks (the cover).

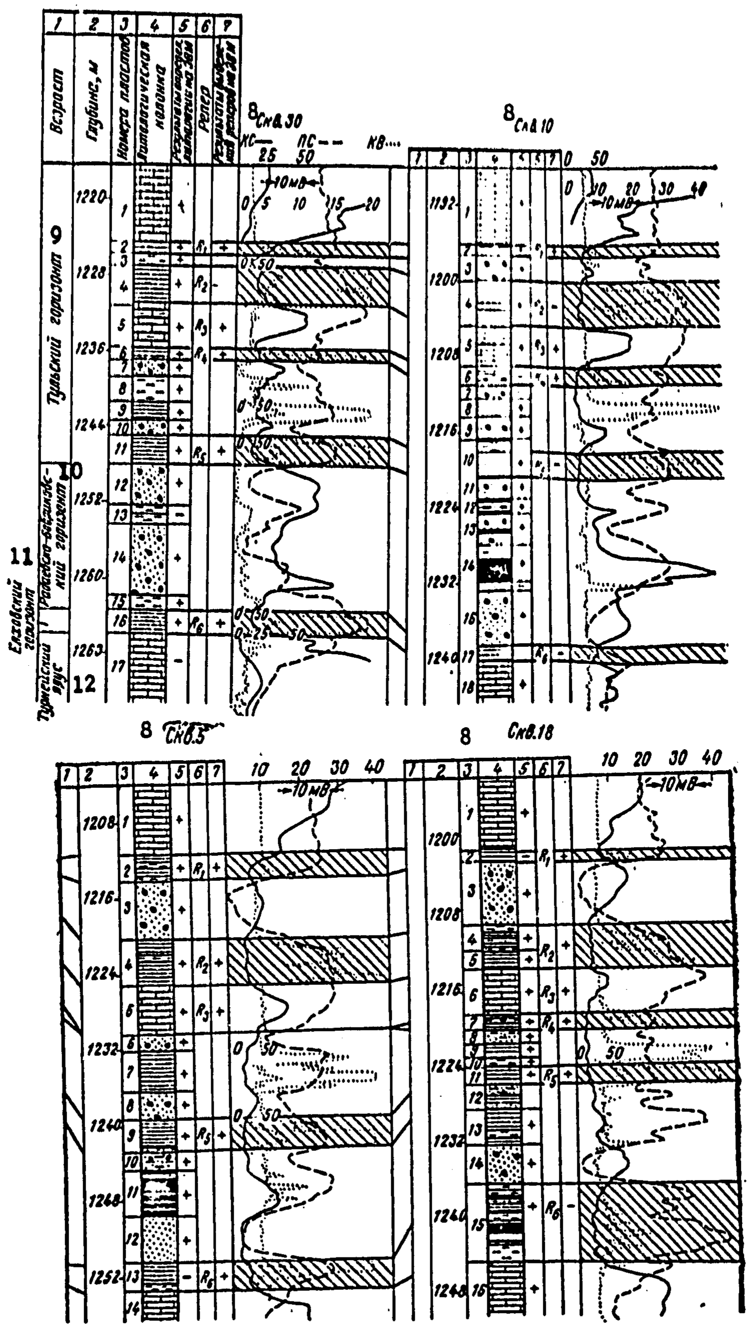


Figure 7. See next page.

Figure 7. Schematic comparison of sections of wells of the Novokhazin area mB = mV

1 -- Age
2 -- Depth, m
3 -- Number of reservoirs
4 -- Lithological column
5 -- Results of lithological determination by computer
6 -- Reference mark
7 -- Results of distinguishing reference marks by computer
8 -- Well
9 -- Tul'skiy horizon
10 -- Radayevskiy-Bobrikovskiy horizon
11 -- Yelkhovskiy horizon
12 -- Turneyskiy stage

For an oil field geophysical complex a producing reservoir is characterized by the following features: a predominance of negative CP indications and low GM's, positive MZ increments, low and medium NGM or NM values. Characteristic of rocks of the cover is a predominance of positive PS indications and high GM values, medium, high and low NGM or NM values and an absence of MZ increment.

The bands distinguished in the carbonate-terrigenous profile of the Middle Carboniferous period are well traced also on territories of Tatariya and Permskaya and Kuybyshevskaya oblasts adjacent to Bashkiriya.

The formation of bands (rhythms) is determined to a considerable degree by the rhythmicity of sedimentation, expressed in a regular alternation in the profile of Middle Carboniferous deposits of reservoirs, represented by purer carbonate rocks and in most by a layer of porous-permeable and dense clayey-carbonate varieties of rocks reflecting transgressive and regressive phases of oscillatory motions.

The question of the start of the rhythms is disputable: some researchers are inclined to start the rhythms with regressive, others with transgressive, and still others with the middle of the phases. Sharing the point of view of researchers who take the transgressive phase to be the start of rhythms, the authors rhythmicity on the alternation of more porous-permeable, less silted up producing reservoirs, concentrated in the lower part of the rhythm, and clayey, dense reservoirs of the upper part of each rhythm.

At the same time, strict rhythmicity of the profile of the Middle Carboniferous is destroyed by the effect of a whole series of other processes which extinguish the boundaries of individual bands and producing reservoirs. This is mainly characteristic of regions in the profiles of which a considerable quantity of clayey material is contained in the producing reservoirs and active processes of dolomitization and sulfatization of rocks occur. In such cases a gradual transition of the producing reservoir to clayey-carbonate dense rock is observed. In proportion to the accumulation of an adequate complex of oil field geological material the boundaries of the bands and producing reservoirs require refinement.

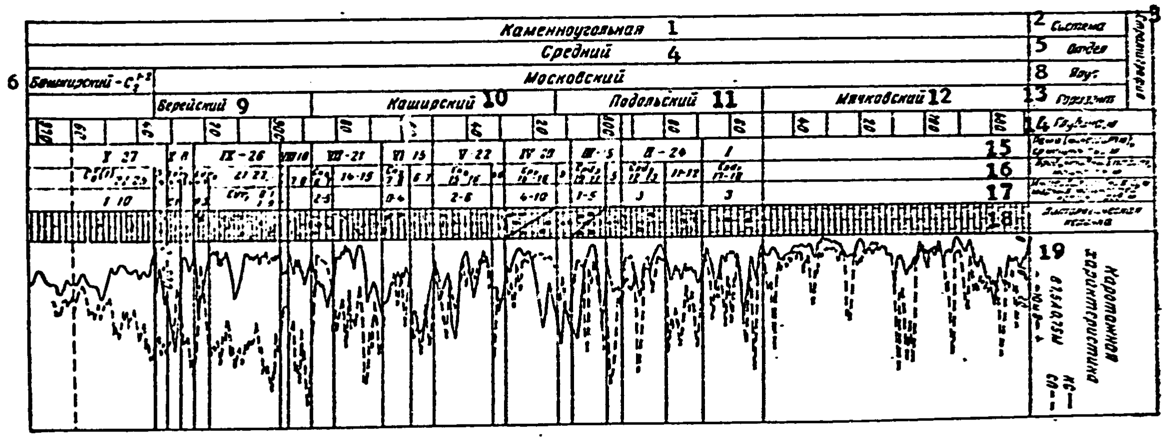


Figure 8. Arlan typical geological-geophysical section of Carbonaceous deposits.

1 -- Carbonaceous
2 -- System
3 -- Stratigraphy
4 -- Middle Moskovskiy
5 -- series
6 -- Bashkirskiy-C_2^{1-2}
7 -- not used
8 -- stage
9 -- Bereyskiy
10 -- Kashirskiy
11 -- Podol'skiy
12 -- Myachkobskiy
13 -- horizon
14 -- Depth, m
15 -- Band (microrhythm), mean thickness, m
16 -- Producing reservoir, thickness, m
17 -- Range of mean total thickness of collectors, m
18 -- Lithological column
19 -- Logging characteristic

In the Middle Carboniferous deposits the distinguishing of rhythmically alternating bands is one of the main aspects in the study of the structure of carbonate rocks and determination of the regularities in the distribution of collectors. In connection with the established rhythmicity of structure of the profile of Middle Carboniferous deposits, characterized by definite features, the possibility of distinguiching bands and reservoirs is considered the first stage in the regional correlation of sections by computer.

Chapter 3. Study of the Heterogeneity of Producing Reservoirs

A very important feature of the geological structure of producing reservoirs, one exerting a substantial influence on the completeness and intensity of the working of oil reserves, is their lithological-facial variability. Used to study variability (heterogeneity) of producing reservoirs are both traditional methods (construction of lithological-facial maps and profiles, maps of thickness, permeability, porosity, etc), and also new geological-statistical methods (estimation of heterogeneity on the basis of the coefficients of zonation, persistence, sandyness, stratification, etc).

Depending on the stage in the organization and working of a deposit, various methods of studying heterogeneity are used [4,34,35]. In the initial stage of investigation of the geological structure a qualitative characterization of the variability of producing reservoirs is sufficient. Maps of thickness, permeability, porosity and other parameters characterizing reservoir collectors are constructed to obtain it. Quantitative estimation of the heterogeneity of reservoirs is also important in the planning and analysis of the working, together with the qualitative characterization. Such an estimation is especially important in studying multireservoir deposits, at which, as a result of heterogeneity of the reservoirs, irregular working of the reservoirs and outrunning of the advance of water through the reservoirs are expressed more sharply and losses of oil are found in zones confined to the tapering-off boundaries of the reservoir collectors.

On the example of the Arlanskoye and other deposits of Bashkiriya we have examined some methodical procedures that permit estimating the degree of heterogeneity of producing reservoirs.

Characteristics of Terrigenous Traps

Some of the indicators of heterogeneity are the structure of the traps of producing reservoirs, their porosity, permeability and granulometric composition, the type and mix of the cement, and also the character of their distribution over the profile and the area. It is natural that the more homogeneous the reservoir the more constant are all those features, and the reverse. Such large multireservoir oil deposits as the Arlanskoye, the Uzen'skoye and others, are characterized by considerable partitioning and variability of the producing reservoirs. As an example of sharply expressed heterogeneity of traps we present a description of the rocks of a terrigenous formation of the Lower Carboniferous of the Arlanskoye and other deposits of Bashkiriya.

The terrigenous deposits of the Lower Carboniferous are some of the principal oil-producing complexes of Volgo-Ural'skaya Oblast. Industrial oil content in the section of the terrigenous formation of Bashkiriya has been established in all of its horizons: the Yelkhovskiy, Radayevskiy, Bobrikovskiy and Tul'skiy. Oil traps are fine-grained sandstones and coarse-grained siltstones which are bedded in the form of lenslike layers among clayey, coaly-clayey and other impermeable rocks. The thicknesses of the separate layers and their quantity are extremely inconstant even within small areas. A very large number of reservoirs and the maximum total thickness (20-30 m) are confined to the northwestern rayons of Bashkiriya--to sections of the Chekmagushevskoye, Mancharovskoye, Arlanskoye, Tatyshlinskoye and other deposits. In the northern half of Bashkiriya, producing reservoirs are traced in the Radayevskiy, Bobrikovskiy and Tul'skiy horizons, and traps are sometimes encountered in the Yelkhovskiy horizon. In the southern half of the territory the principal producing reservoirs are sandy-siltstone rocks of the Radayevskiy and Bobrikovskiy horizons.

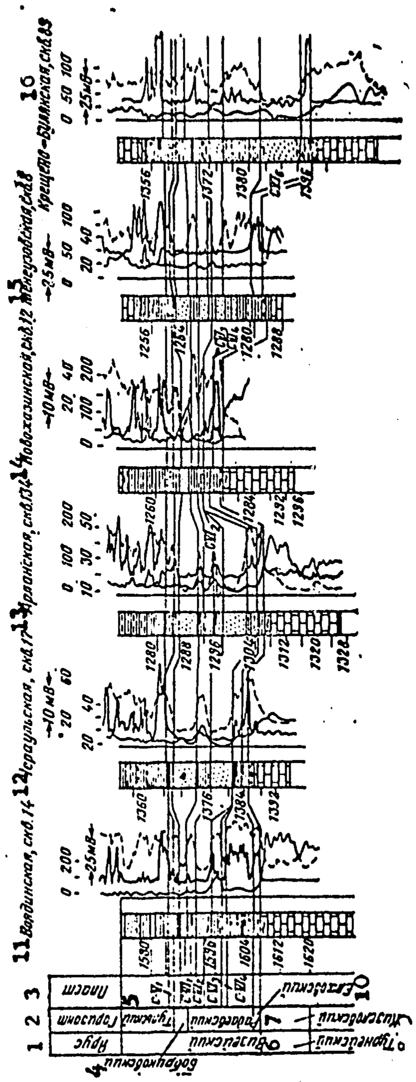
The traps of different horizons and reservoirs have mainly an identical material composition, but differ in their trap properties, the type of cementing. the quantity of cement, the grain size, etc. A characterization of traps is presented on the basis of study of their mineralogical and granulometric compositions and detailed investigation of the mineralogical composition of the clay cement. Classed as traps are sandy-siltstone rocks with a porosity of at least 10 percent and a permeability of at least 1 mD.

The rock traps of the Radayevskiy and Bobrikovskiy horizons are regarded as reservoir C-VI, and in the section of the Tul'skiy horizon the following seven reservoirs are distinguished: C-I, C-II, C-III, C-IV^0, C-IV, C-V and C-VI^0.

Reservoir C-VI is composed mainly of fine-grained quartzous sandstones, at times of coarse-grained sandy siltstones. The siltstones are characteristic mainly of reservoirs with small thicknesses and are encountered very often in sections of the southern part of Bashkiriya. A reservoir is usually partitioned into several partings, the thickness and number of which is inconstant: they vary from 2 to 6 in number. In most rayons the reservoir thicknesses are poorly maintained and in a short distance the rock traps are replaced by impermeable varieties, but sections with a monolithic structure of reservoir C-VI are sometimes encountered (Figure 14).

The sandy-siltstone rocks have dark- and light-gray colorations, depending on the degree of clayiness and coaliness. The quartz grains in the rocks are poorly cemented, and at the same time several types of cementing have developed: contact, sharply incompletely porous, porous and basal (Figure 15).

The cement mix also is different--clayey and limy. At times pyrite, siderite and aphrosiderite are observed in the cement (Figure 15b). The pores are of an intergranular, very rarely interaggregate character, irregular and resembling slits, at times of round form with dimensions of 0.01-0.6 mm along the length of the axis. The pores often are connected by channels up to 1-1.5 mm in length and not more than 0.4 mm in width. Tapering out microfissures with a width of 0.02 to 1.0 mm are encountered in the clayey siltstones and sandstones.



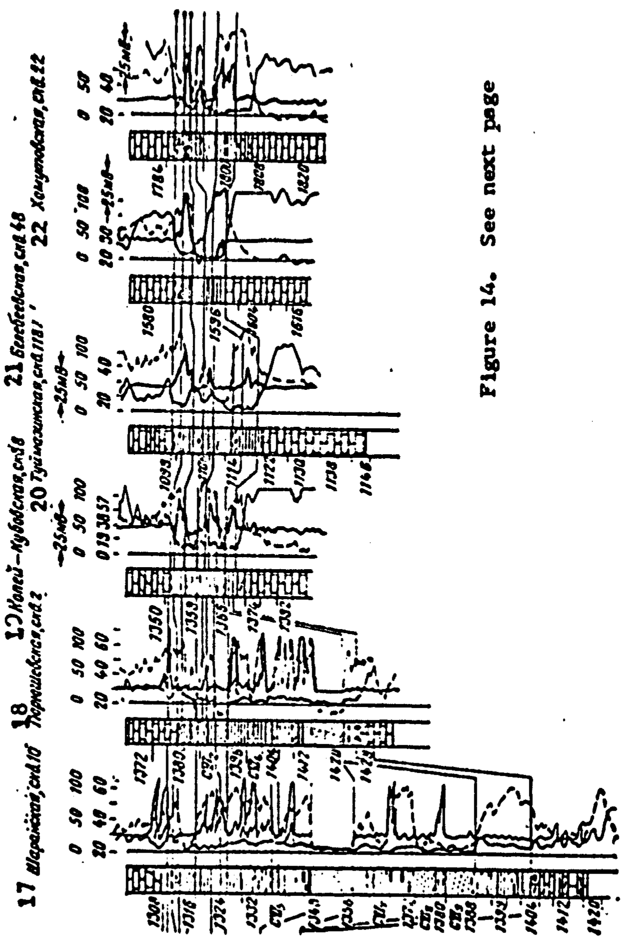


Figure 14. See next page

Figure 14. Schematic comparison of sections of reservoir C-VI along the line of the Voyadinskoye-Demskoye deposits mB = mV

1 -- stage
2 -- horizon
3 -- reservoir
4 -- Bobrikovskiy
5 -- Tul'skiy
6 -- Vizeyskiy
7 -- Radayevskiy
8 -- Turneyskiy
9 -- Kizelovskiy
10 -- Yelkhovskiy
11 -- Voyadinskaya, well 14
12 -- Cheraul'skaya, well 17
13 -- Arlanskaya, well 1-.
14 -- Novokhazinskaya, well 12
15 -- Meneuzovskaya, well 8
16 -- Kreshcheno-Bulyakskaya, well 83
17 -- Sharanskaya, well 10
18 -- Tyuryushevskaya, well 2
19 -- Kopey-Kubovskaya, well 8
20 -- Tuymazinskaya, well 1187
21 -- Belebeyevskaya, well 48
22 -- Khomutovskaya, well 22

The clay, calcite and coaly detritus are distributed in collectors irregularly, in the form of lenticular selvedges, layers and irregular sections. Such a distribution of the material causes horizontal, slightly slanting, wavy and inclined layering and a fine-dense structure of the rock.

The presence of layering in the rocks exerts a substantial influence on permeability, determined in the direction perpendicular to the stratification (pr). For layered examples this value of the permeability is considerably lower than that determined parallel to the stratification (pp).

In the case of homogeneous texture of collectors the $k_{pp}:k_{pr}$ ratio varies from 0.93 to 1.13, and for a layered texture k_{pp} is always larger than k_{pr} and the $k_{pp}:k_{pr}$ ratio varies from 3.8 to 18.0. If the layered texture of the collectors is reflected in the ratio $k_{pp}:k_{pr}$, then the fine-dense texture (dense inclusions of calcite) exert an influence on the capacity of the collectors. Sandy and siltstone rocks with a dense structure have high permeability with relatively low porosity. The permeability of samples of reservoir C-VI is fairly high even when the porosity is below 15% (364-696 mD). For such low values of the porosity in rocks with a layered texture the permeability does not exceed 10-20 mD.

The mineralogical composition of the clayey cement of the rock collectors of reservoir C-VI is mainly kaolinitic; in the lower partings of the sandstones one notes, as a rule, an admixture of hydromica and disordered mixed layer mineral of the type of montmorillonite-hydromica [6]. Kaolinite is represented by clearly expressed hexagonal authigenic crystals 0.5-2.0 microns or larger in size (Figure 16a, b). In accordance with the mineralogical composition of the clayey cement the values of the absorption capacity also are found, usually equal to 10-15 mg-equiv/100 g and increasing to 20 mg-equiv/100 g at the bottom of the reservoir (Figure 17).

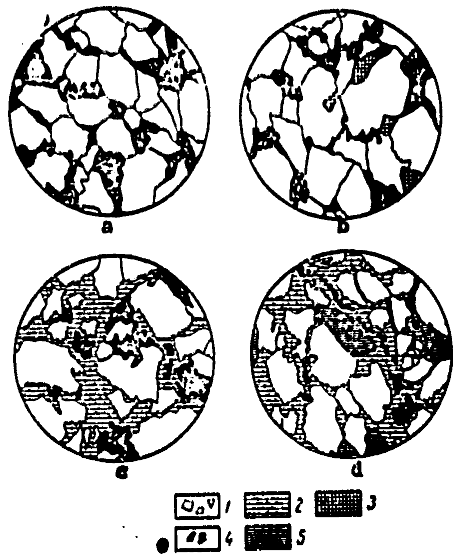


Figure 15. Sketches of slides. a -- sandstone, quartzous, fine-grained, siltstone with contact cementing. X100. Reservoir C-VI (Novokhazino, well 4605, 1220.1-1221.1 m interval; b -- sandstone quartzous, fine-grained with contact cementing and not-completely porous cement. X100. Reservoir C-VI (Novokhazino, well 4769, 1233.1-1237.8 m interval); c -- sandstone, quartzous, fine-grained with clayey-coaly cement of the not-completely porous type. X100. Reservoir C-VI (Novokhazino, well 4759, 1233.1-1237.8 m interval); d - sandstone, quartzous, fine grained, siltstone with clayey-coaly and calcite cement of porous and not-completely porous types. X100. Reservoir $C\text{-}V_1$ (Novokhazino, well 4632, 1220.8-1226.0 m interval. 1 -- quartz; 2 -- coaly-clayey material; 3 -- picrite; 4 -- hollow pores; 5 -- coaly material.

The small content of the pelitic fraction (3-5 percent, rarely 7-10 percent) in the soluble part ($\leqslant$10 percent), the good sorting of the fragmented material (S_0 = 1.5 - 2.5) and the low absorption capacity assure high, although sharply fluctuating trap properties of the rocks.

A very large number of determinations of porosity and permeability were made on core samples from sections of the Arlanskoye deposit. Thus for the deposit the porosity values fluctuate from 11 to 31 percent, the mean porosity factor is 23.6 percent, and the permeability fluctuates from 0.1 to 11 D.

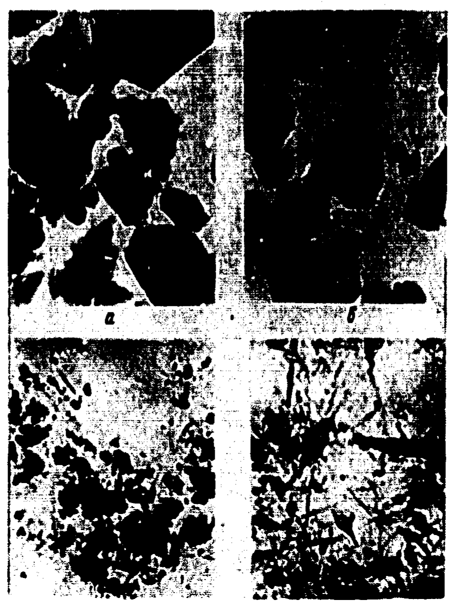


Figure 16. Electron microscope photographs. a -- fraction <0.001 mm from sandstone of reservoir C-VI. X18,000. (Arlan, well 343, 1273.5-1277.5 m interval); b -- fraction <0.001 from sandstone of reservoir C-VI. X18,000. (Arlan, well 183, 1252.3-1255.1 m interval); c -- fraction <0.001 mm from sandstone of reservoir C-IC. X5000. (Arlan, well 291, 1201-1206.4 m interval); d -- fraction <0.001 mm from sandstone of reservoir C-II. X10,000. (Novokhazino, well 3908, 1215.3-1216.6 m interval).

The siltstones have poor trap properties: their porosity varies from 10 to 26 percent and the permeability is 10-3650 mD in the "pp" direction and does not exceed 896 mD in the "pr" direction. According to the classification scheme of A. I. Krinari the traps belong in classes 1 and 2 and subclasses 1 and 2 [22,42].

Reservoir C-VI^{0} is encountered as a trap in sections of the Arlanskoye deposit, where its thickness reaches 4 to 5 m, and upon increase of the

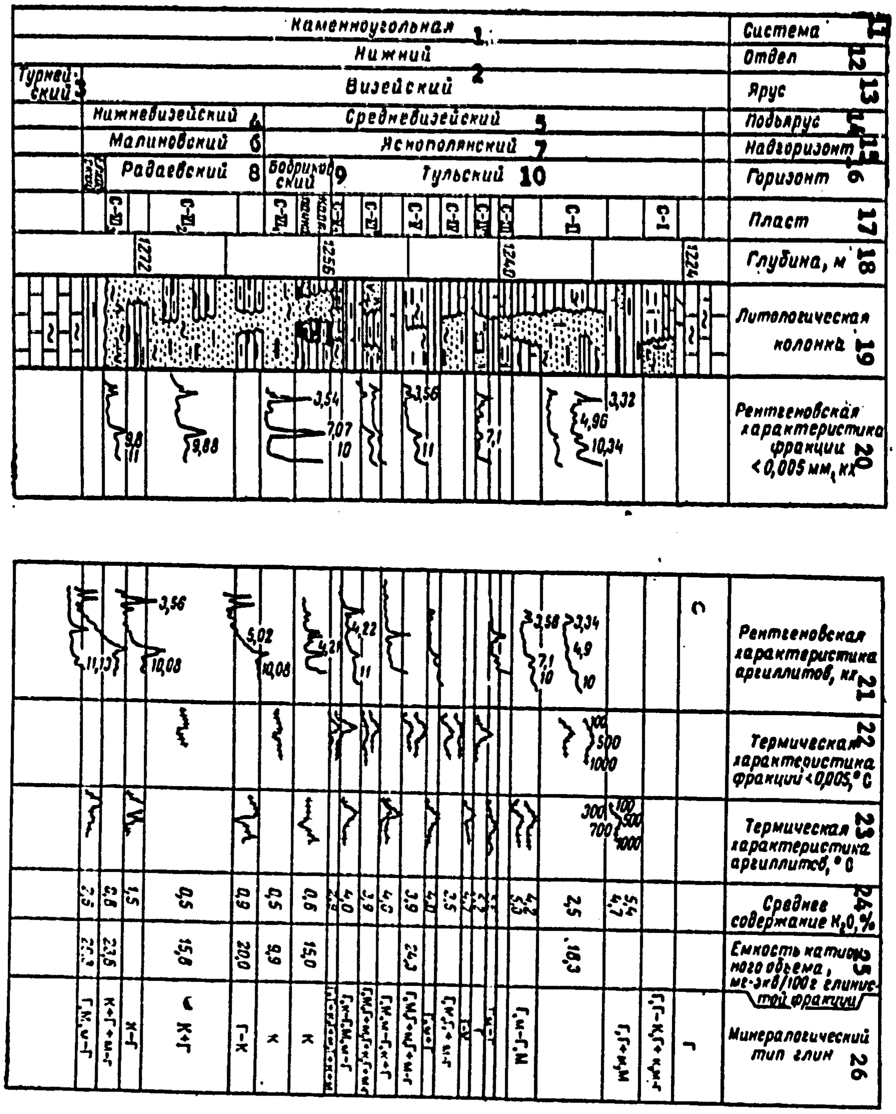


Figure 17. See next page.

Figure 17. Characteristics of clay minerals of sections of the terrigenous formation of the Lower Carboniferous of oil deposits of northwestern Bashkiriya

1 -- Carboniferous
2 -- Lower Vizeyskiy
3 -- Turneyskiy
4 -- Lower Vizeyskiy
5 -- Middle Vizeyskiy
6 -- Malinovskiy
7 -- Yasnopolyanskiy
8 -- Radayevskiy
9 -- Bobrikovskiy
10 -- Tul'skiy
11 -- system
12 -- series
13 -- stage
14 -- substage
15 -- Suprahorizon
16 -- Horizon
17 -- Reservoir
18 -- Depth, m
19 -- Lithological column
20 -- X-ray characteristics of fraction < 0.005 mm, kXu
21 -- X-ray characteristics of argillites, kXu
22 -- Thermal characteristics of fraction < 0.005, °C
23 -- Thermal characteristics of argillites, °C
24 -- Mean K_2O content, %
25 -- Capacity of cation volume, mg-equiv/100 g of clayey fraction
26 -- Mineralogical type of clays

clayiness the thickness decreases to 1 m. The fine-grained quartzous sandstones and coarse-grained siltstones of reservoir C-VI^0 often are poorly sorted out and always are to some degree clayey and coaly. The clayey-coaly material is distributed extremely irregularly, and S_0 varies from 2 to 3.5.

The content of clayey and carbonate material in the cement of rocks of reservoir C-VI^0 at times is high, reaching 10-37 and 25 percent respectively. In addition, often noted in the cement are late diagenetic formations of kaolinite, gypsum and anhydrite which considerably worsen the trap properties. When there is a high content of cementing material (> 20 percent), pore and basal types of cementing are developed. Often the content of cementing material over the section and over the area varies sharply in the range of 5-15 percent, and the type of cementing in that case is mixed contact and not completely porous (Figure 18a, b). In the latter case the collector properties of the reservoir rocks are high and medium, and the oil saturation is relatively uniform. The rock porosity varies from 12 to 24 percent and the permeability from 5 to 600 and occasionally to 800 mD.

The mineralogical composition of the clayey material is mainly hydromicaceous. Two varieties of hydromica are noted, clastic and authigenic. The latter considerably worsens the trap properties. Often noted is montmorillonite and a mixed layered mineral of the type of montmorillonite-hydromica or kaolinite. The porosity and permeability values of traps of classes 3, 4 and 5 and subclasses 2, 3, 4 and 5 fluctuate in a wide range.

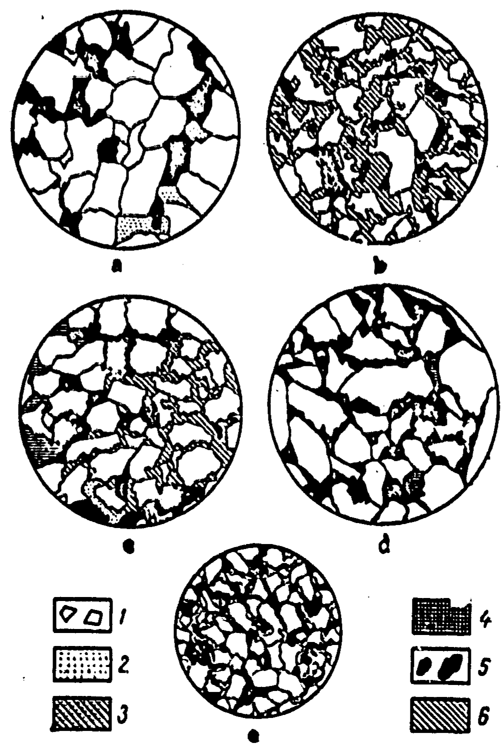


Figure 18. Sketches of slides. a -- quartzous sandstone, fine-grained, with contact cementing. Packing of quartz grains is dense. X100. Reservoir C-VI^{0} (Novokhazino, well 4741, 1222.0-1224.2 m interval); b -- quartzous siltstone, coarse grained, sandy with coaly cement of porous and not completely porous types of cementing. X100. Reservoir C-VI^{0} (Novokhazino, well 4605, 1212.0-1215.2 m interval); c -- quartzous sandstone, fine-grained, siltstone with coaly, clayey sections with calcite cement of the porous, not completely porous and basal types. X100. Reservoir C-IV (Novokhazino, well 4633, 1223.1-1227.2 m interval); d -- quartzous sandstone, fine-grained, siltstone with contact type of cementing. Pyrite in the coals of individual pores. X100. Reservoir C-II (Novokhazino, well 4617, 1205.9-1207.2 m interval); e -- quartzous sandstone, fine-grained, siltstone with clayey cement of not completely porous and contact types. X65. Reservoir C-V (Arlan, well 59, 1273.9-1278.0 m interval). 1 -- quartz; 2 -- clay; 3 -- coaly-clayey material; 4 -- pyrite; 5 -- hollow pores; 6 -- coaly material.

Reservoir C-V consists of fine-grained sandstones and coarse-grained siltstones. The quartz grains are cemented by coaly-clayey, more rarely, carbonate cement. The types of cementing are: pore, basal, and rarely contact (Figure 18d). The rocks are very coaly. The intergrain and inter-aggregate pores are of irregular and slitlike form, and the dimensions along the long axis are 0.02-0.46 mm.

Depending on the type of cementing and the quantity of cementing material, the values of the porosity and permeability vary, being 19 percent and 0.4 D on the average. The fluctuations of those parameters are considerable within the limits of individual areas and deposits. Thus, on sections of the Arlanskoye deposit the porosity varies from 10 to 25 percent and the permeability from 0.02 to 2.6 D. The collectors belong to class 3, at times class 1 and 2.

The thickness of receiver C-V fluctuates strongly; if it consists of a good trap, its thickness is 3-4 m, but if the reservoir is composed of clayey siltstone its thickness cannot be more than 1 m. Very great development of sandstones in that reservoir is observed in sections of Northern Bashkiriya (Figures 2 and 4).

The quantity of the pelitic fraction usually is about 10 percent or more and its mineralogical composition, as in reservoir C-V^0, is mainly hydromicaceous, but a substantial admixture of montmorillonite and a mixed layered component of the type of montmorillonite-hydromica is often noted, and at times a clayey cement is encountered, composed completely of montmorillonite, which considerably worsens the properties of the rocks. The fraction < 0.005 mm was enriched with carbonaceous material and pyrite. The absorption capacity of the < 0.005 mm fraction, as in other reservoirs with a mainly hydromicaceous composition, is very small--15-20 mg-equiv/100 g, which is probably explained by good crystallization of the minerals (Figure 17).

Reservoir C-IV has a thickness of about 2 m. In some sections a confluence of reservoirs C-IV and C-V is noted, and then the total thickness reaches 8-20 m. The reservoir is composed of both well-sorted out sandstones and siltstones and of siltstone-clayey varieties of rock. In thicker reservoirs the fragmented material of the rocks is relatively well-sorted out and, on the contrary, thin reservoirs are characterized mainly by a siltstone composition, and the rocks in that case are clayey and limy. The sorting factor varies from 2.0 to 3.0. The quartzous material is cemented by clayey, clayey-coaly, and more rarely carbonate cement. The type of cementing is porous and contact, at times basal (Figure 18c). During the contact type of cementing there is not more than 3-5 percent of the pelitic fraction in the sandstones, and 2-4 percent of the soluble. Correspondingly, the reservoir has good trap properties, a porosity of 22-26 percent and a permeability of up to 3800 mD. The pelitic fraction of the rocks is strongly enriched with coaly organic material. The mineralogical composition of the clayey cement is hydromicaceous, montmorillonitic and montmorillonite-hydromicaceous with a K_2O content of 3-5 percent. The hydromica consists in fragmentary and authigenic modifications (Figure 16).

The porosity of reservoir C-IV is 19-22 percent on the average and the permeability is about 500 mD, although the fluctuations of those parameters are very large over both the section and the area. The porosity and permeability are 12-30 percent and 0.1-3.8 D respectively. The collectors are mainly of class 3, but at times layers of traps of classes 1 and 2 and subclasses 1, 2 and 3 are encountered.

Reservoirs C-IV^0 and C-III usually consist of strongly limy siltstones, clayey to different degrees, with a crumpled texture. Sections of lenticular development of those reservoirs, composed of sandstones with a thickness of up to 2-4 m, are encountered sporadically.

The type of cementing in the rocks of reservoirs C-IV^0 and C-III is extremely heterogeneous: porous and basal, and not completely porous in sorted out sections. The quartz grains are cemented by calcite, zeolites, gypsum, anhydrite, pyrite and to a lesser degree clayey matter composed mainly of hydromica and enriched with carbonaceous organic matter. The hydromica consists of isometric-lamellar and long splintery modifications. The authigenic variety of hydromica in the sections of the Arlanskoye deposit in association with zeolites worsens the permeability of the rocks. From time to time hollow pores of irregular and slitlike form with dimensions of up to 0.02 mm on the long axis are encountered in the cement. Often noted in the rocks simultaneously are several types of cementing with an irregular distribution of the cementing material, as a result of which the traps have an irregular oil saturation (separate sections, thin layers, lenses, tracks of mudeaters, etc). The sorting coefficient fluctuates from 2.0 to 3.5.

In view of the irregular sorting of the fragmented material the trap properties of the reservoirs fluctuate sharply: the porosity from 9-13 to 24 percent and the permeability from the practically impermeable to 413 mD, and rarely to 700-800 mD.

Reservoir C-II with an average thickness of 5-7 m is widespread mainly in the northwestern rayons of Bashkiriya. In the southern and eastern directions there is displacement of the terrigenous rocks of that part of the section by carbonate rocks (Figures 3 and 4). Increased thicknesses (up to 15 m) connected with facial replacements of the underlying sediments are most widespread on the Novokhazinskaya and Arlanskaya areas (Figure 19).

In separate sections the reservoir is broken down by clayey-siltstone rocks into two, more rarely three partings, the most enduring of which is the upper parting C-II$_{up}$.

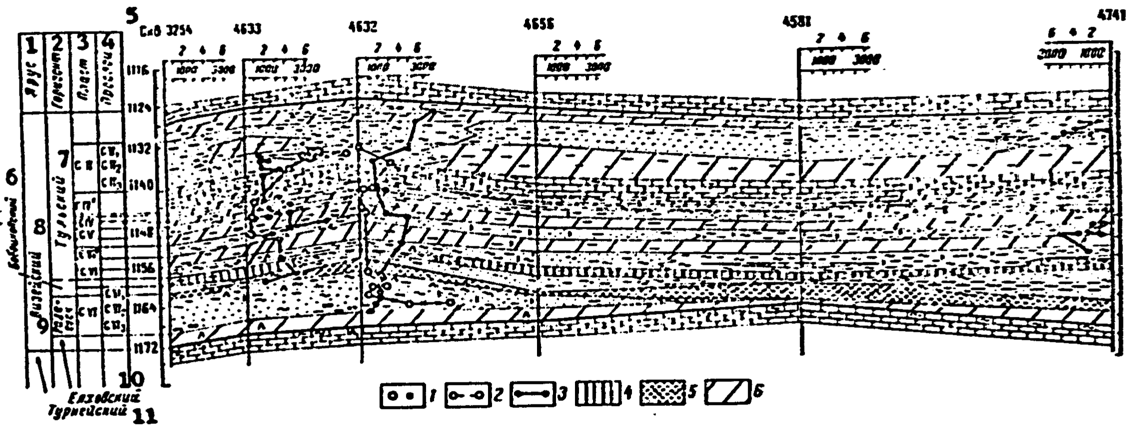


Figure 19. Schematic geological profile of the Novokhazin test section of the Arlanskoye oil deposit. 1 -- depth at which sample was taken; 2 -- curve of variation of permeability over the section; 3 -- curve of variability of the sorting coefficient over the section; 4 -- argillites of kaolinitic composition; 5 -- argillites of hydromicaceous-kaolinitic composition; 6 -- argillites of hydromicaceous-montmorillonitic composition.

Reservoir C-II is composed of gray fine-grained, rarely with an admixture of medium-grained, quartzous sandstones and sandy siltstones. The quartzous grains are cemented by a clayey material, at times to a considerable degree clayey and pyritized; in isolated sections calcitic and zeolitic cements are encountered. The predominant type of cementing is contact, more rarely porous, not completely porous and basal (Figure 18d). The pores are irregular and of slitlike form. The sorting factor is 1.3-2.0, rarely 2.5.

The content of the pelitic fraction in the traps usually is less than 10 percent, and of the soluble part--about 4 percent. Due to the enrichment of the fraction smaller than 0.005 mm with clayey material and pyrite the clayey minerals are in a subordinate quantity and consist of allothigenous and authigenous hydromica (Figure 16d), authigenous kaolinite and mixed layered mineral of the type of montmorillonite-hydromica. The low values of the absorption capacity (12-24 mg-equiv/100 g of sample) cause the good trap properties of the reservoir. The rock porosity varies from 10 to 28 percent and the permeability from 10 to 6300 mD. The traps belong in classes 1 and 2 and subclasses 1, 2 and 3.

For the traps of reservoir C-II, just as for the rocks of reservoir C-VI, in view of their heterogeneous structure, the influence of textural features of the siltstone-sand rocks on their filtering properties in various directions is noted. In traps with a massive (homogeneous) structure the $k_{pp} \cdot k_{pr}$ ratio has relatively high values (2.2-21.0). In traps with a dense texture the permeability values also remain high (300-3000 mD) at low and medium values of the porosity (9-20 percent).

Reservoir C-I, developed in sections of the northwestern areas of Bashkiriya (the Arlanskoye deposit) is composed of strongly limy and clayey sandy-siltstone rocks, often with a crumpled texture. Its thickness is 1 to 3.5 m. The fragmentary material is poorly sorted out and is cemented with clayey, coaly-clayey, carbonate and often zeolite cement. The mineralogical composition of the clay is mainly hydromicaceous. The cementing is of the porous, basal, or rarely the contact type. The porosity is 10-24 percent and the permeability 1.0 to 1850 mD. The trap properties improve when the thickness of the reservoir increases. The traps usually belong to classes 1 and 2 and subclasses 1, 2 and 3. Both the cement mix and the types of cementing in the rocks are mixed, as a result of which irregular oil-saturation of the rocks is observed.

Thus in the degree of sorting out, the packing of the quartz grains, the quantity and quality of the cementing material, and also the type of cementing, producing reservoirs of the terrigenous formation of the Lower Carboniferous differ considerably from one another.

Reservoirs V-VI and C-II have the widest development, large thicknesses and better trap properties in the section of the terrigenous formation of the Lower Carboniferous. Contact and not completely porous types of cementing usually are widespread in them, with a content of not more than 10 percent of the pelitic fraction and a soluble part of less than 5 percent.

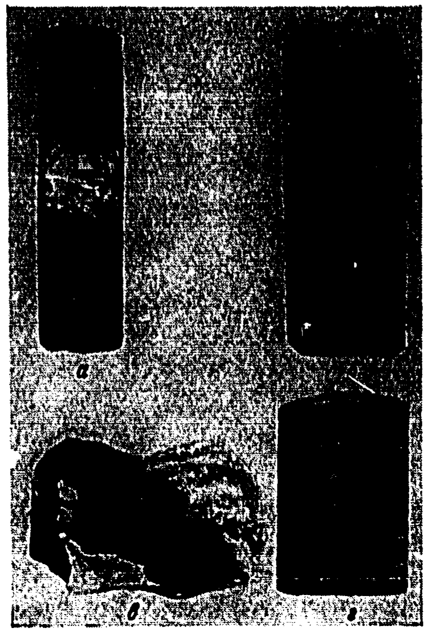


Figure 20. Core samples. a -- oil-saturated sandstone (above), gray limy sandstone without features of oil-saturation (middle) and dark-gray siltstone, coaly-clayey (below). Reservoir C-VI (Arlan, well 288, 1225.6-1230.6 m interval); b -- sandy, oil-saturated siltstone with frequent coaly features on planes of stratification and traces of cores of plants. Reservoir C-VI (Arlan, well 287, 1228-1233 m interval); c -- oil-saturated sandstone with large inclusions of irregular form of gray sandstone. Reservoir C-VI (Novokhazino, well 4632, 1237.0-1239.7 m interval); d -- thin crumpling of oil-saturated sandstone and gray siltstone (light). Reservoir C-VI (Arlan, well 292, 1221-1226 m interval).

A mixed type of cementing: contact, not completely porous, porous and basal, predominates mainly in reservoirs of the Tul'skiy horizon, with the exception of reservoir C-II. The presence of the last two types of cementing is especially characteristic of reservoirs C-IV^0, C-III and C-I.

The trap properties of all the reservoirs depend on the total content of the cementing material: clayey, coaly, calcitic, and also on the quantity of the fine-silty fraction, and on their distribution in nature. When the amount of cement is less than 10 percent, a mainly kaolinitic and hydromicaceous-kaolinitic composition of the clayey fraction is present and there are contact and not completely porous types of cementing, the rocks have a permeability of over 500 mD. Sandy-siltstone rocks, the clayey cement of which consists simultaneously of kaolinite, hydromica, montmorillonite and mixed-layered formations, have poor trap properties.

The above-described various types of cementing and the irregular distribution of the cementing material create in reservoirs of the terrigenous formation of the Lower Carbonian a sharply expressed macro- and microheterogeneity of the traps.

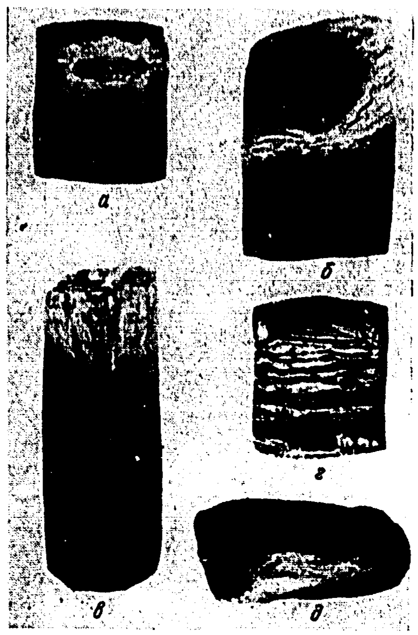


Figure 21. Core samples. a -- thin interstratification of oil-saturated sandstone, gray siltstone and black coaly argillite. Large nodule of pyrite above. Reservoir C-VI (Arlan, well 292, 1221-1226 m interval); b -- horizontally layered sandstone with pocket of erosion filled with oil-saturated sandy material. Reservoir C-VI (Novokhazino, well 4632, 1232-1234 m interval); c -- oil-saturated sandstone in the form of large spots and limy gradually changes into a layer of strongly limy, fissured and cavernous sandstone. The fissures and caverns are filled with coaly-pyritic material. The limy sandstone is not saturated with oil. Reservoir C-VI (Arlan, well 289, 1209.8-1214.8 m interval); d -- thin interstratification of dark-gray argillite and irregularly oil-saturated sandstone. Reservoir C-II (Arlan, well 291, 1196-1201 m interval); e -- oil-saturated sandstone with lenticular layers of dark-gray sandstone, slightly saturated with oil.as a result of the development of porous cement of zeolitic composition. Reservoir C-II (Novokhazino, well 3908, 1214.5-1215.3 m interval).

Permeated and dense varieties of rocks are often distributed in the form of lenses, thin (millimeter and centimeter) partings, sections of irregular form, etc. Heterogeneity of collectors is manifested especially graphically in the detailed study of core material. Heterogeneity of the sandy-siltstone deposits of reservoirs C-VI and C-II of the Arlanskoye deposit is connected mainly with lamination of the rocks (horizontal, oblique inclined and lenticular) and also with the coagulate type of cementing (Figures 20 and 21).

In view of that, traps with similar values of porosity (18-23 percent) have a difference in permeability of 3-4 times and, on the contrary, some are encountered with relatively good permeability and low porosity.

The sandy-siltstones of rocks of reservoirs C-V, C-IV, C-III and C-I have a high degree of heterogeneity as a result of the great variety of textures, simultaneous development of various types of cementing and a sharply expressed irregular distribution of the cementing material. In the traps of those reservoirs, even within the limits of the 10-cm column cores, one can encounter sections with both the contact type of cementing--with an insignificant content of clayey, carbonate material, and with the basal type--with an almost complete absence of voids between the grains (Figure 18e).

The sandstones and siltstones of those sections have not only a layered texture but also textures of destruction (turbidization of sediments, sliding, erosion inside formations, caused by the paths and burrows of mud-eaters, etc). All these types of textures give the rock such a complex "crumpled" appearance that it is difficult even to trace the interconnection of individual oil-saturated sections of the trap.

Naturally, such heterogeneity of the rock trap complicates extremely the working of oil reservoirs.

Distinctive Features of the Distribution of Terrigenous Traps and Their Heterogeneity

It is a very difficult task to completely include the flooding of individual reservoirs in multireservoir deposits when they are jointly worked, since producing reservoirs, as noted above, have sharply different trap properties and oil-bearing contours, and the areas of development of traps and dense rocks of individual reservoirs do not coincide in the plane.

At large deposits, as a rule, pressure series are planned to maintain the pressure in the main reservoirs. Oil field geologists face the task of working out measures to draw all the oil reserves of a producing formation into active development. That problem is solved most often by installing or organizing additional pressure wells. To designate the sections where placement of additional pressure wells will be most rational it is necessary to study the distinctive features of the distribution of producing reservoirs by area, make a thickness analysis and determine the parameters of the heterogeneity of traps.

Often under the conditions of a multireservoir deposit the oil pools confined to the various reservcirs have such a complex structure that the map or plan where the oil pool outlines of all the pools are plotted simultaneously is illegible (and cannot be used to solve specific problems in analysis of the development). In that case it is advisable to break the section down into several lithological members.

The producing reservoirs of the Arlanskoye deposit are grouped in three members.

Taken as the lower member is the section included between the Turneyskiy limestones and the first downward Tul'skiy argillites (reference mark 8_1) or their analogs, that is, the Radayevsko-Bobrikovskiy deposits, including reservoir C-VI.

The middle member includes producing reservoirs C-VI^0, C-V, C-IV, C-IV^0 and the argillite layers separating them. The lower boundary of the member is drawn along the bottom of reference mark 8_1, the upper along that of argillite reference mark 6, and on the Novokhazinskaya area--along the bottom of the 4-m limestone confined to the middle part of the Tul'skiy deposits. The zones of development of producing reservoirs of that member do not coincide in the plane.

The principal distinctive feature of that part of the section is the discontinuous development of individual reservoirs and their screening by dense rocks on a considerable part of the area (Figure 22).

By the upper member is understood the part of the section that includes rocks from the roof of reservoir C-IV^0 to the roof of the terrigenous formation; mica is included in producing reservoirs C-III, C-II and C-I.

Reservoir C-VI (lower member) is widespread on the territory of Bashkiriya. Three major zones are traced from the thicknesses of the collectors of that reservoir.

The first zone included the Arlanskaya and Novokhazinskaya areas, with the Dyurtyulinskaya group adjacent to it from the south and the Cheraul-Or'yebashskoye deposit from the east (Figures 23,24,25). Here the traps have a thickness of zero to 30 m. More often they have a thickness of 4-12 m. A considerable portion of the area is occupied by zones of replacement of collectors by dense rocks. Up to four partings of traps with different characteristics are distinguished in the section.

The highest trap properties are noted in the second parting from the bottom (C-VI$_2$).

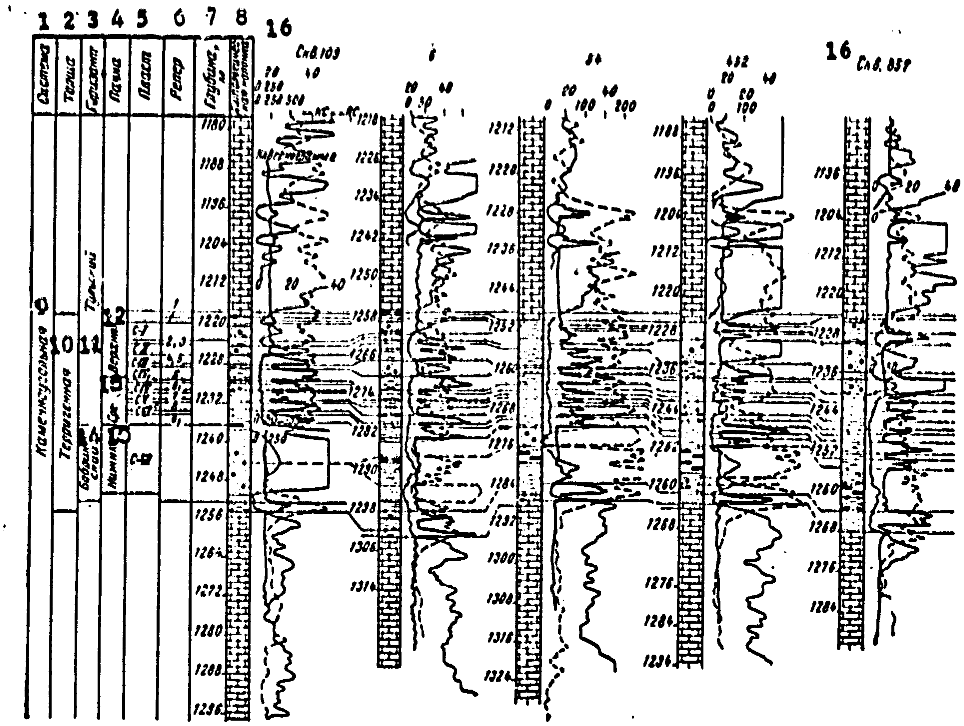


Figure 22. Zonation of sections of the Arlanskaya area.

1 -- System
2 -- Formation
3 -- Horizon
4 -- Member
5 -- Reservoir
6 -- Reference mark
7 -- Depth, m
8 -- Lithological column
9 -- Carboniferous
10 -- Terrigenous
11 -- Tul'skiy
12 -- Upper
13 -- Middle
14 -- Bobrinskiy
15 -- Lower
16 -- Well

That parting is very widespread on the deposit. The maximum thickness and its largest constant development are noted in the northern part of the Novo-khazinskaya area (10-19.4 m).

In the central part the thicknesses are reduced to 8 to 12 m. In the western half of the central part a large number of sections ("spots") of replacement of the traps by dense rocks appear. In the southern part of the section, dense rocks alternate with zones of traps of small thickness.

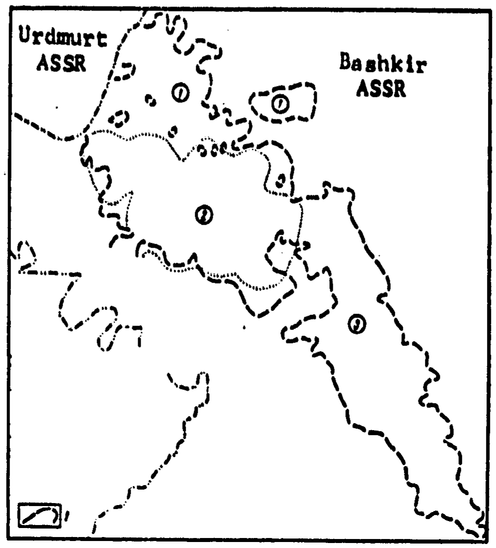


Figure 23. The Arlanskoye oil deposit. 1 -- provisory boundary of deposit; areas: 1 -- Nikolo-Berezovskaya; 2 -- Arlanskaya; 3 -- Novokhazinskaya.

The mean value of the arenosity factor for reservoir C-VI of the Arlanskaya area is 0.48 (Table 1).

In the central part of the Arlanskaya area the value of the arenosity factor is not greater than 40 percent (Figure 26). On the background of those values zones of replacement of traps have been developed. The sections bounded by the isolines from zero to 20 percent form the main part of the central part of the area. The traps there have small thicknesses, are more clayey and are confined to the upper part of the section. The zone of reduced values of the arenosity factor extends far to the west and east, including partially the Ashitskiy and Urtaul'skiy sections, and only to the south of the zone is a small section noted where a sharp contact of zero zones with maximum values of the factor (82-67 percent) is observed. Rarely on the background of low values of the factor are small scattered sections with values of the factor of up to 60 percent and higher noted.

Marginal sections of the Arlanskaya area are distinguished by higher values of the arenosity factor (from 60 to 93 percent). Those zones are also partitioned by sections with lower values of the factor.

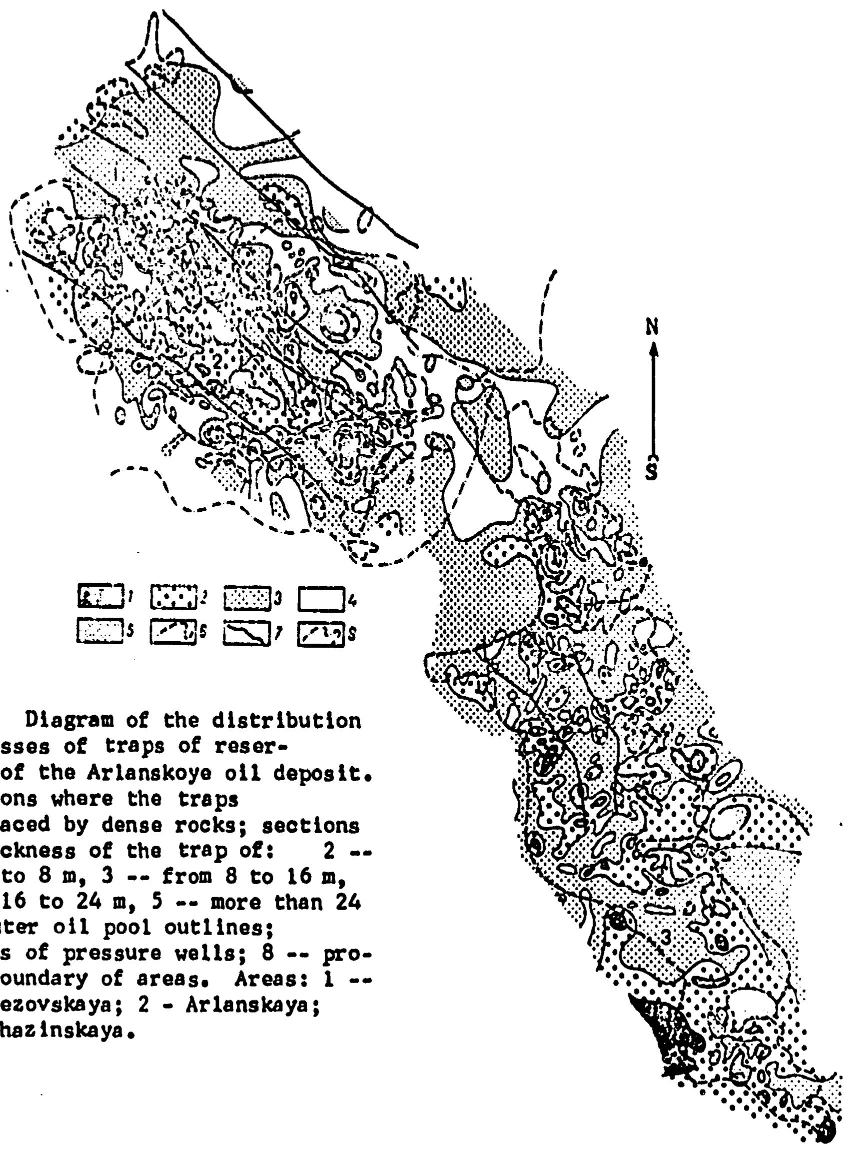


Figure 24. Diagram of the distribution of thicknesses of traps of reservoir C-VI of the Arlanskoye oil deposit. 1 -- sections where the traps been displaced by dense rocks; sections with a thickness of the trap of: 2 -- from zero to 8 m, 3 -- from 8 to 16 m, 4 -- from 16 to 24 m, 5 -- more than 24 m; 6 -- outer oil pool outlines; 7 -- series of pressure wells; 8 -- provisional boundary of areas. Areas: 1 -- Nikolo-Berezovskaya; 2 - Arlanskaya; 3 -- Novokhazinskaya.

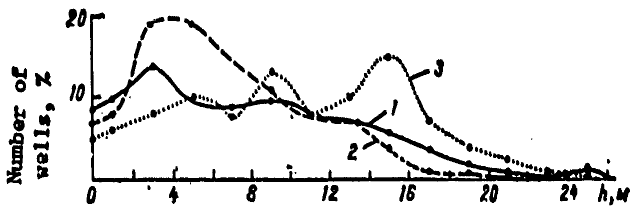


Figure 25. Distribution of total thicknesses of reservoir C-VI by areas of the Arlanskoye deposit by number of wells. Area: 1 -- Arlanskaya; 2 -- Novokhazinskaya; 3 -- Nikolo-Berezovskaya.

Table 1. Mean values of the coefficients of heterogeneity of the Bobrikovsko-Radayevskiy deposits (reservoir C-VI) of the Arlanskaya area

Участки (A)	(B) Среднее значение коэффициентов		
	(C) песчанистости	(D) связанности	(E) расчлененности
1 Ашитский	0,48	0,32	2,10
2 Нагаевский	0,33	0,48	1,49
3 Актанышбашевский	0,44	0,28	1,96
4 Сакловский	0,57	0,21	2,48
5 Арланский (I)	0,48	0,16	2,41
6 Арланский (II)	0,42	0,43	1,87
7 Краевой	0,61	0,33	1,93
8 Уртаульский	0,54	0,40	1,60
9 Николо-Березовский (I)	0,54	0,41	1,90
10 Николо-Березовский (II)	0,57	0,36	1,87

Key: A -- Sections
B -- Mean value of coefficients
C -- of arenosity
D -- of coherence
E -- of zonation
1 -- Ashitskiy
2 -- Nagayevskiy
3 -- Aktanyshbashevskiy
9 -- Saklovskiy
10 -- Arlanskiy (I)
11 -- Arlanskiy (II)
12 -- Krayevoy
13 -- Urtaul'skiy
14 -- Nikolo-Berezovskiy (I)
15 -- Nikolo-Berezovskiy (II)

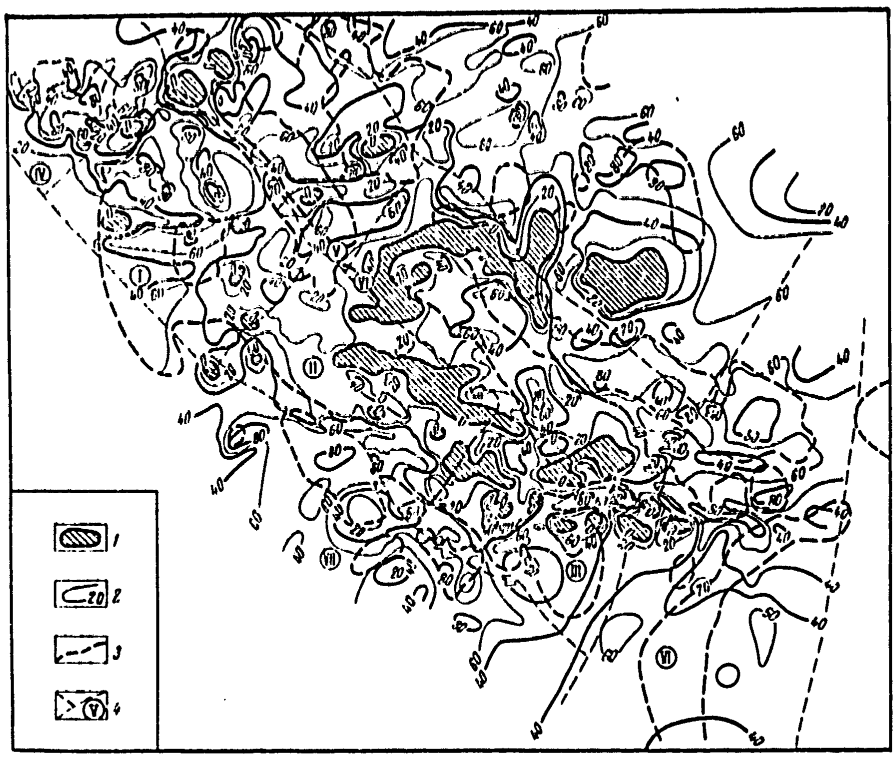


Figure 26. Diagram of the distribution of sandstones of reservoir C-VI in the lower producing member of the Arlanskaya area. 1 -- sections where collectors of reservoir C-VI have been displaced by dense rocks; 2 -- isolines of percentage content of sandstones; 3 -- outer oil pool outline; 4 - boundary and number of sections of the development.

Analysis of the map of equal values of the arenosity coefficient and the oil pool outlines of pools of the Bobrikovsko-Radayevskiy deposits the Arlanskaya area shows that the purely oil sections of pools of reservoir C-VI are confined to sections with low values of the coefficient, and that their water and oil parts correspond to regions with high values of the coefficient or the reservoir here is completely saturated with water.

The mean value of the zonation coefficient on the Arlanskaya area for reservoir C-VI is 1.92. The minimum values of the coefficient (1.49-1.60) were noted in the eastern part of the area. High values (2.48-2.41) were traced in the northwestern part, where the interstratification of dense with porous layers was noted in the lower, water-saturated part of reservoir C-VI. On the remaining sections the value of the coefficient varies from 1.87 to 2.10.

The coherence coefficient for reservoir C-VI has a mean value of 0.32. Its fluctuation is very great on the various sections (Table 1). Thus, reservoir C-VI on the Arlanskaya area has a high degree of heterogeneity. On isolated sections the arenosity coefficient varies by a factor of 2, that of coherence by one of 3 and of zonation by one of 1.5.

In 30 percent of the wells reservoir C-VI consists of monolithic sandstone with a maximum thickness of 26 m. In approximately the same number of wells the reservoir is broken down into two separate interstratifications (Figure 27).

Fairly often, sandstone traps alone constitute the upper part (22 percent of wells drilled), corresponding to the upper interstratification, and the lower is replaced by siltstones and clayey rocks. In 8 percent of the wells only the lower part, corresponding to the lower interstratification, consists of sandstones.

The zone of junction of the sandy interstratifications ("monolithic sections") of reservoir C-VI on the Ashitskiy section is widely developed in the vault part of the structure. On its eastern limb the reservoir is broken down into two interstratifications. The coaly-clayey sections within the reservoir in that section have thicknesses of 0.8 to 6.4 m. "Tongues" of dense rocks create as it were "corridors" among the zones of junction; the latter are very favorable paths, however, for the movement of liquid through the reservoir. This is confirmed by working data. Such "corridors" of reservoir C-VI were the paths for a breakthrough of waters on the Ashitskiy section in the initial stage of development (1962-1963), when the pool regime had not yet been established.

On the Novokhazinskaya area, in contrast with the Arlanskaya, a large number of interstratifications of dense rocks, breaking the collector down into separate interstratifications, is noted in reservoir C-VI. Up to three interstratifications of coaly-clayey rocks is traced in the section of the Bobrikovsko-Radayevskiy deposits.

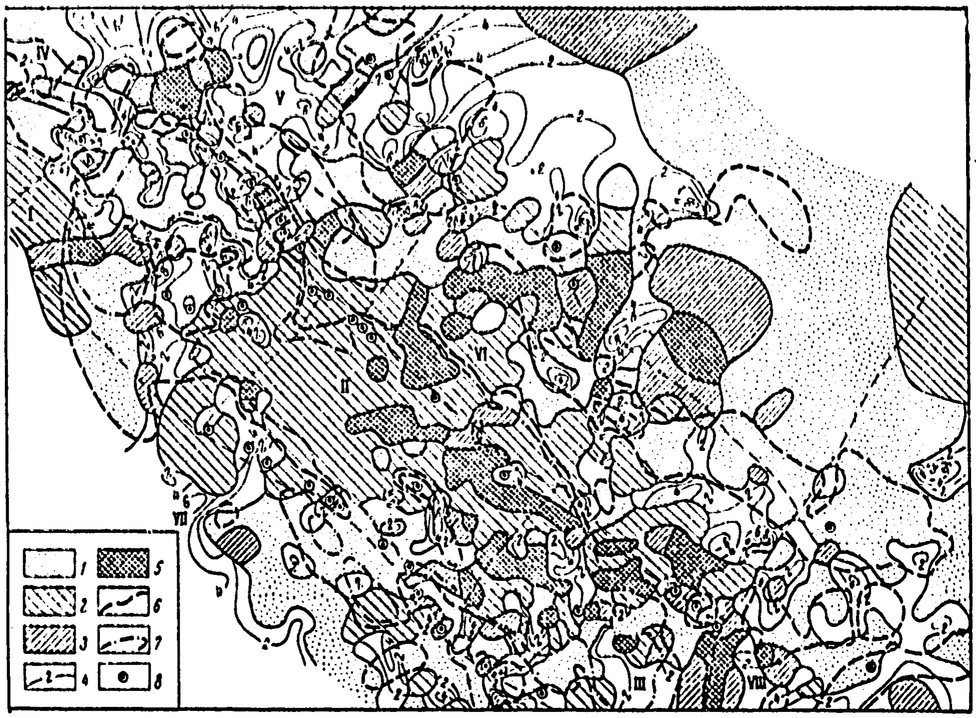


Figure 27. Diagram of the development of types of sections of reservoir C-VI of the Arlanskaya area. 1 -- sections that are developments of a "monolithic" reservoir; 2 -- sections that are developments of traps only in the upper part of the reservoir; 3 -- the same, of traps only in the lower part; 4 -- the same, of traps in both the upper and lower parts and of the coaly-clayey section between them (isopachous lines of clayey rocks were drawn every 2 m); 5 -- sections that are replacements of the reservoir by dense rocks; 6 -- outer oil pool outline; 7 - inner oil pool outline; 8 - pressure wells.

The monolithic reservoir on the Novokhazinskaya area has a smaller extent than on the Arlanskaya and is encountered mainly on the northern and eastern wings of the structure (Figure 28). On the main part of the structure, however, two layers of traps predominate, separated by argillite with a thickness of 1.2 m (on the south) to 7.2 m (on the north). Zones where there are no traps intersect in a narrow band the central part of the area. They are encountered in isolated spots also in the southern part of the area

(7 percent of the wells drilled). Traps on the Novokhazinskaya area are more of the same type with respect to heterogeneity than on the Arlanskaya. The arenosity coefficients fluctuate from zero to 0.41, the coherence coefficients from 0.74 to 1 and the zonation coefficients from 1.25 to 2.6 (Table 2).

Table 2. Coefficients of heterogeneity of the Bobrikovsko-Radayevskiy deposits (reservoir C-VI) for sections of the Novokhazinskaya area

A Коэффициент	B Участки						
	1	2	3	4	5	6	7
1 Песчанистости	0,41	0,36	0,51	0,27	0,37	0,40	0,14
2 Связанности	0,98	0,74	0,98	0,83	0,99	0,95	1
3 Расчлененности	1,9	1,10	1,4	1,4	1,25	1,7	2,6

Key: A -- Coefficient
B -- Sections
1 -- Arenosity
2 -- Coherence
3 -- Zonation

East of the Novokhazinskaya area, at the Andreyevskoye oil deposit the thicknesses of the traps increase from 4 to 25 m from the vault of the structure toward the limbs. The producing reservoirs also are heterogeneous, and two interstratifications are distinguished in the section--C-VI_1 and C-VI_2, which are further broken down into several layers. On areas of the Dyurtyulinskaya group of deposits the thicknesses of the traps are mainly 4-12 m.

The second zone of traps of reservoir C-VI includes the Sauzbashevskoye and Mancharovskoye deposits and the Chekmagushevskaya oil-bearing area adjacent on the southeast. The thicknesses of the traps , increase to 50 m. Thicknesses of 12 to 20 m predominate. No zones of replacement of traps considerable in area were discovered. In the section one can trace up to six interstratification of traps with different characteristics. The trap properties of the rocks are high on the whole. At the Mancharovskoye deposit the sections of development of interstratifications of traps in the plane do not always coincide. The mean value of the arenosity coefficient is 0.51, and of the zonation coefficient, 3.4.

Tuymazinsko-Shkapovskiy Rayon, areas of the Serafimovskaya group, the Kopey-Kubovskoye deposit, etc, are classified in the third zone. In that zone the thicknesses of the traps fluctuates from zero to 25 m. The zones of replacement of traps form extensive fields and occupy a considerable part of the area. Distinguished in the section are two interstratifications of sandstones, characterized by inconstant, relatively poor trap properties and discontinuity of development. At times the sandstones of the two

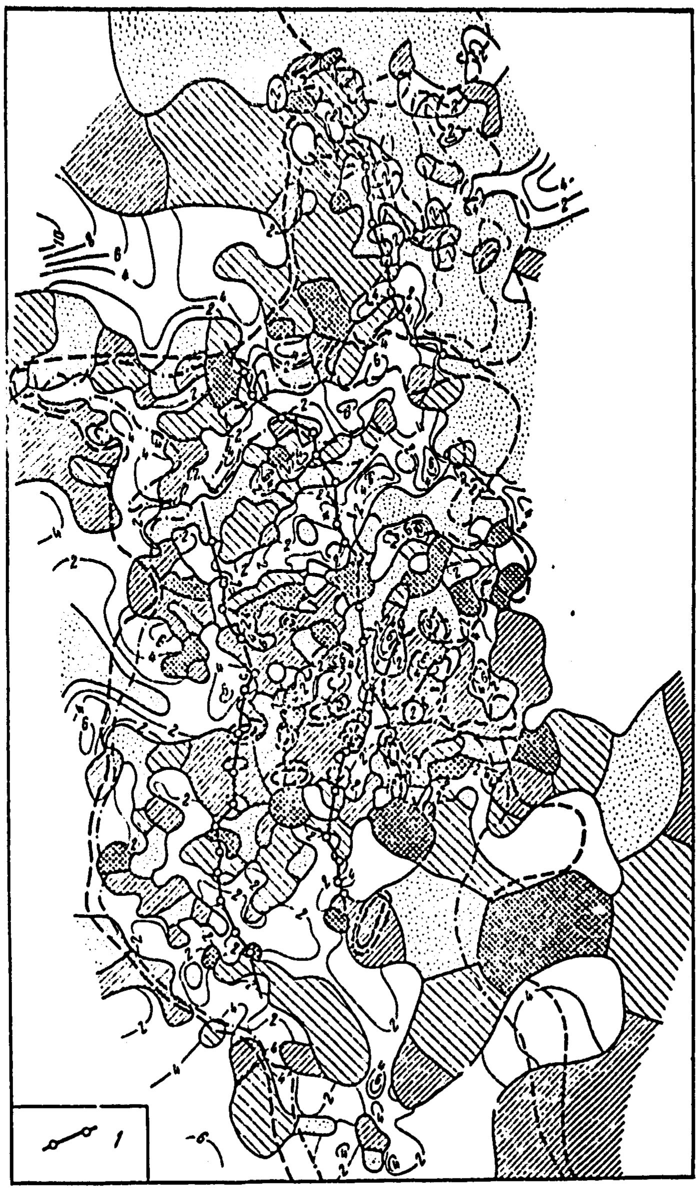


Figure 28. Diagram of the development of types of sections of reservoir C-VI of the Novokhazinskaya area.

1 -- series of pressure wells. Remaining designations as for Figure 27.

interstratifications converge and form a monolithic reservoir with a thickness of 9 to 14 m. In the central and northeastern parts of the Tuymazinskoye deposit are considerable zones of replacement of traps by dense rocks. On a large part of the area, traps with a thickness of up to 4 m are widespread.

The producing reservoirs of the Tul'skiy horizon on the territory of Bashkiriya have far less development than the Bobrikovsko-Radayevskiy. On the basis of the predominant thickness of the traps and the presence of lithological and geophysical reference points two zones of producing reservoirs are provisionally distinguished.

In the first zone are regions of Bashkiriya, including the Novokhazinskaya, Or'yebash-Cheraul'skaya, Chetyrman-Igrovskaya, Kuzbayevskaya and other areas. In sections of this zone the total thickness of traps of the Tul'skiy horizon predominate over the thickness of traps of reservoir C-VI, and in sections an interstratification of limestone with a thickness of 4 to 5 m is noted; interstratifications of argillites 8_1, 8 and 7 have correlational value; reservoir C-II has relatively small thicknesses (5 to 10 m) and wide distribution over the area; considerable thicknesses of reservoirs C-IV, C-V and C-VI^0 are observed in some sections.

The second zone includes the Arlanskaya, Nikolo-Berezovskaya, Sauzbashevskaya and other areas. In the sections of this zone the total thickness of traps of the Tul'skiy horizon is equal or somewhat smaller than the thickness of reservoir C-VI; in comparison with the first zone the reservoirs become more clayey, limestone interstratifications disappear, and argillites acquire the significance of lithological reference marks (8_1, 8, 7, 6, 3, 2); producing reservoir C-I appears in the section; the thickness of the traps of reservoirs C-II, C-IV, C-V and C-VI^0 are reduced; the traps have a more discontinuous character of development.

To the south of those zones (Tuymazinskoye, Shkapovskoye and also the Mancharovskaya group of deposits, etc) traps are not present in the section of the Tul'skiy horizon.

Producing reservoirs of the middle member also occur in both zones. Traced in the base of the member is reservoir C-VI^0, the greatest development of which is observed on the Novokhazinskaya area of the Arlanskoye deposit. Traps are discovered in the sections of 40 percent of drilled wells. Their thickness fluctuates from 0.6 to 5.6 m. Predominant development of sandy-siltstone rocks is noted on the eastern sloping limb of the structure; in the vault part, the traps are in the form of small lenses.

In the Arlanskaya area traps have been discovered in only 8 percent of the wells drilled; a considerable portion of those wells is beyond the contour of oil bearing of the pools. The thickness of reservoir C-VI^0 varies from 0.6 to 3.6 m.

On the Nikolo-Berezovskaya area, traps have been discovered in 18.3 percent of the wells drilled. Two thirds of them are in the water-saturated part of the reservoir. The The trap thicknesses fluctuate from 0.6 to 2.2 m. On the whole, thicknesses of reservoir C-VI^0 of 1 to 2 m predominate at the Arlanskoye deposit.

At the Andreyevskoye deposit the thickness of reservoir C-VI^0 fluctuates from 0.8 to 3.4 m. The reservoir is facially variable and large zones of replacement of trap are distinguished.

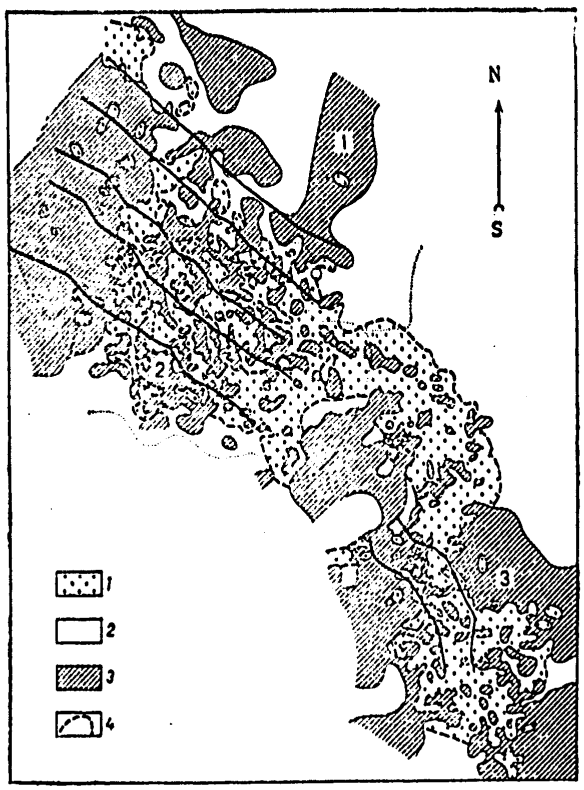


Figure 29.. Diagram of the distribution of collectors of reservoir C-V of the Arlanskoye oil deposit.
1 -- oil pools; 2 -- water-bearing traps; 3 -- sections of replacement of traps by dense rocks; 4 -- outer oil pool outline.

Reservoir C-V has a wider distribution on isolated areas of the Arlanskoye deposit (Figure 29). The reservoir thickness fluctuates from 0.6 to 5 m on the Novokhazinskaya and to 3 m on the Arlanskaya and Nikolo-Berezovskaya areas. On a considerable portion of the Novokhazinskaya area the zones of development of traps of reservoirs C-V and C-VI^{0} coincide in the plane.

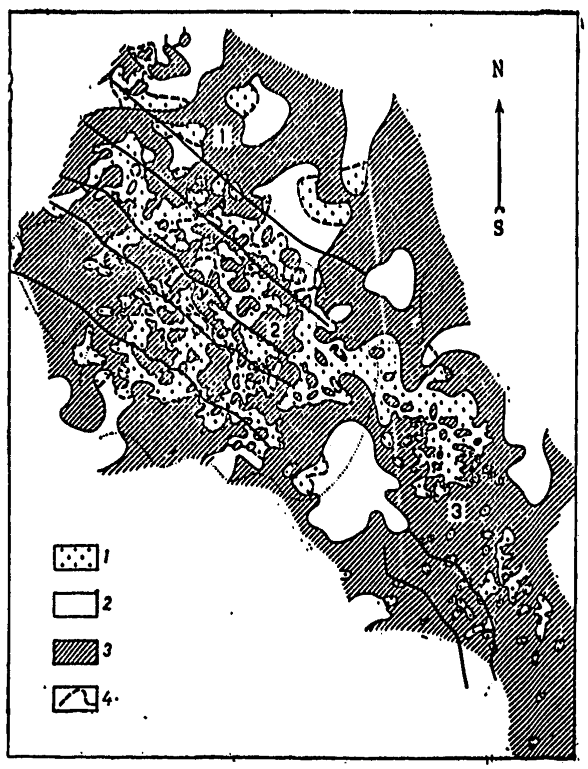


Figure 30. Diagram of the distribution of traps of reservoir C-IV of the Arlanskoye oil deposit. Designations as for Figure 29.

On the Chetyrmanskaya, Igrovskaya and Kuzbayevskaya areas, reservoir C-V has a lenticular development. Its thickness reaches 6 m. On the Chetyrmanskaya area the zones of traps are widespread in the form of two bands. At the Andreyevskoye deposit the thickness of reservoir C-V fluctuates from 0.8 to 2.6 m; the rocks are sharply facially variable.

Reservoir C-IV is lenticularly developed. It is most widespread on the Nikolo-Berezovskaya and Arlanskaya areas (Figure 30). On the Novokhazinskaya area, traps have been encountered on small sections.

The traps of reservoir C-IV^0 have a limited distribution. The reservoir thicknesses do not exceed 2 m. There is a thin trap in the western part of the Sauzbashevskaya area. At all other deposits the reservoir V-IV^0 is composed mainly of dense clayey limy siltstones. And only in the sections of the Tatyshlinskoye and Yugomashevskoye deposits is considerable development of the reservoir C-IV^0 observed. The total thickness of the interstratifications of its traps in that region reaches 10 m, on account of which an increase in the thickness of the middle member on the whole is observed.

The producing reservoirs in the medium member at all deposits of Bashkiriya have strong zonation and sharp lithological-facial variability. For example, the arenosity coefficient of traps of the middle member of the Arlanskaya area is 0.21. This coefficient was determined as the quotient from division of the total thickness of the traps of the producing reservoirs C-IV^0, C-V, C-IV and C-VI^0 by the total thickness of the member. For the area the value of the coefficient fluctuates in a wide range (Table 3).

Table 3 Coefficients of heterogeneity for reservoirs of the middle member of the Arlanskaya area

Участки 1	2 Выдержанность пластов				3 Песчанистость	4 Расчлененность
	C-IV°	C-IV	C-V	C-VI°		
5 Ашитский	0,01	0,17	0,14	0,02	0,17	1,38
6 Нагаевский	0,01	0,61	0,56	0,03	0,22	1,71
7 Актанышбашевский	0,01	0,53	0,65	0,07	0,19	1,87
8 Саклoвский	0,02	0,07	0,02	0,14	0,15	1,09
9 Арланский (V)	0	0,26	0,41	0,03	0,16	1,44
10 Арланский (VI)	0	0,66	0,59	0,03	0,18	1,84
11 Краевой	0	0,33	0,46	0,15	0,10	1,48
12 Уртаульский	0,37	0,51	0,78	0,11	0,22	1,95
13 Николо-Березовский (I)	0,03	0.57	0,50	0,11	0,21	1,27
14 Николо-Березовский (II)	0,13	0,45	0,68	0,09	0,22	1,77

Key:
1 -- Sections
2 -- Consistency of reservoirs
3 -- Arenosity
4 -- Zonation
5 -- Ashitskiy
6 -- Nagayevskiy
7 -- Aktanyshbashevskiy
8 -- Saklovskiy
9 -- Arlanskiy (V)
10 -- Arlanskiy (VI)
11 -- Krayevoy
12 -- Urtaul'skiy
13 -- Nikolo-Berezovskiy (I)
14 -- Nikolo-Berezovskiy (II)

The zonation coefficient for the middle part of the section indicates the number of reservoirs encountered simultaneously on one and the same section of the Arlanskaya area. Its mean value for the area is 1.70. Testifying to the great discontinuity of the producing reservoirs is the development on the sections of not more than two reservoirs out of four. The coefficient of lithological consistency is subject to considerable variation (Table 3).

In the central part of the Arlanskaya area, combination of the traps of reservoirs C-IV and C-V in the plane is observed. Such zones have an unusual form and in a number of sections merge with one another by narrow channels. The area of their "joint" development amounts to 37 percent of the total area of development of traps and contains about 52 percent of the total number of such reservoirs.

Reservoir C-V is distributed over 37 percent of the area, and reservoir C-IV over 20 percent of the total area of oil-bearing traps. On a considerable part of the Arlanskaya area (about 40 percent) there are no traps in the middle part of the section. Analogous correlations between zones of development of reservoirs are observed at the Novokhazinskaya and other areas.

In view of the fact that in most sections of oil-bearing regions of Bashkiriya the upper part of the Tul'skiy horizon consists of carbonate rocks, the traps of the upper member have relatively little development. Producing reservoirs of that member are encountered mainly within the second zone.

Reservoir C-III of the upper member is developed very widely in the northern half of the Arlanskoye deposit. On the Nikolo-Berezovskaya area, traps have been discovered in 46 percent of the wells drilled, on the Arlanskaya in 23 percent, on the Vyatskaya in 68 percent, and on the Novokhazinskaya they have been replaced mainly by limestones. In the northwestern part of the Arlanskaya area, sandy-siltstone traps of that reservoir are traced in the form of lenses with a thickness of 1 to 6 m. On the Nikolo-Berezovskaya area thicknesses of 1.5-2.5 m predominate, and of 9 m on one section.

Producing reservoir C-II is widely distributed in comparison with other reservoirs of the upper member. Some reduction of the thicknesses of traps and areas of their development in northwestern direction (Figures 31 & 32) is observed at the Arlanskoye deposit. The traps are contained in the sections of 87 percent of the wells drilled on the Novokhazinskaya, 83 percent on the Arlanskaya and 63 percent of the Nikolo-Berezovskaya areas.

In the main section of the Novokhazinskaya area sandstone thicknesses of 4 to 6 m predominate. Sections with maximum thicknesses of 8 to 15 m are distinguished on their background. Noted in the region of the southwestern limb of the structure is an alternation of zones of the middle thicknesses of sandstones with zones of thin traps and sections of their complete replacement.

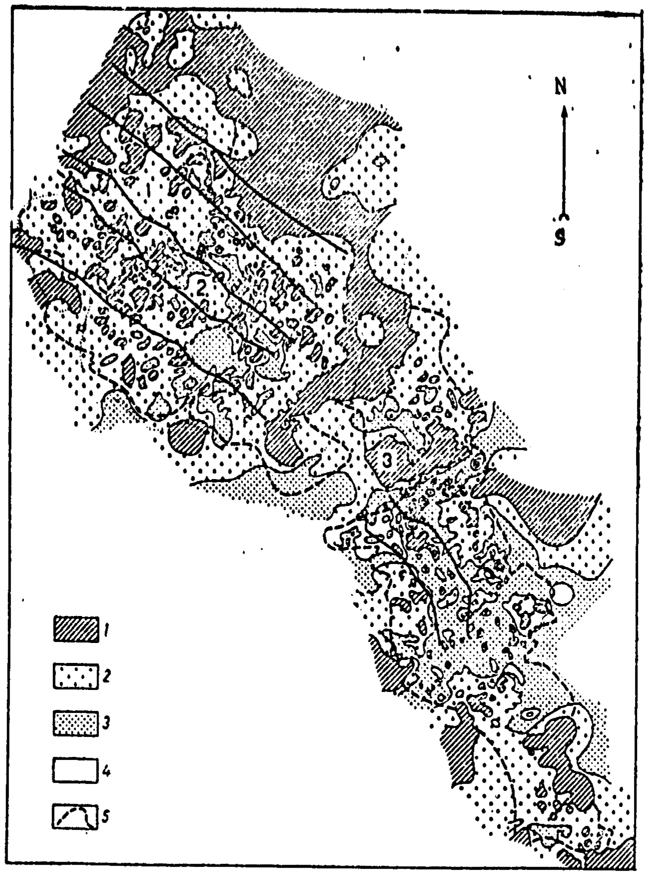


Figure 31. Diagram of the distribution of thicknesses of traps of reservoir C-II of the Arlanskoye oil deposit.
1 -- sections of replacement of traps by dense rocks;
2 -- sections with a thickness of traps of zero to 8 m;
3 -- sections with a thickness of traps of 8 to 16 m;
4 -- sections with a thickness of more than 16 m;
5 -- outer oil pool outline.

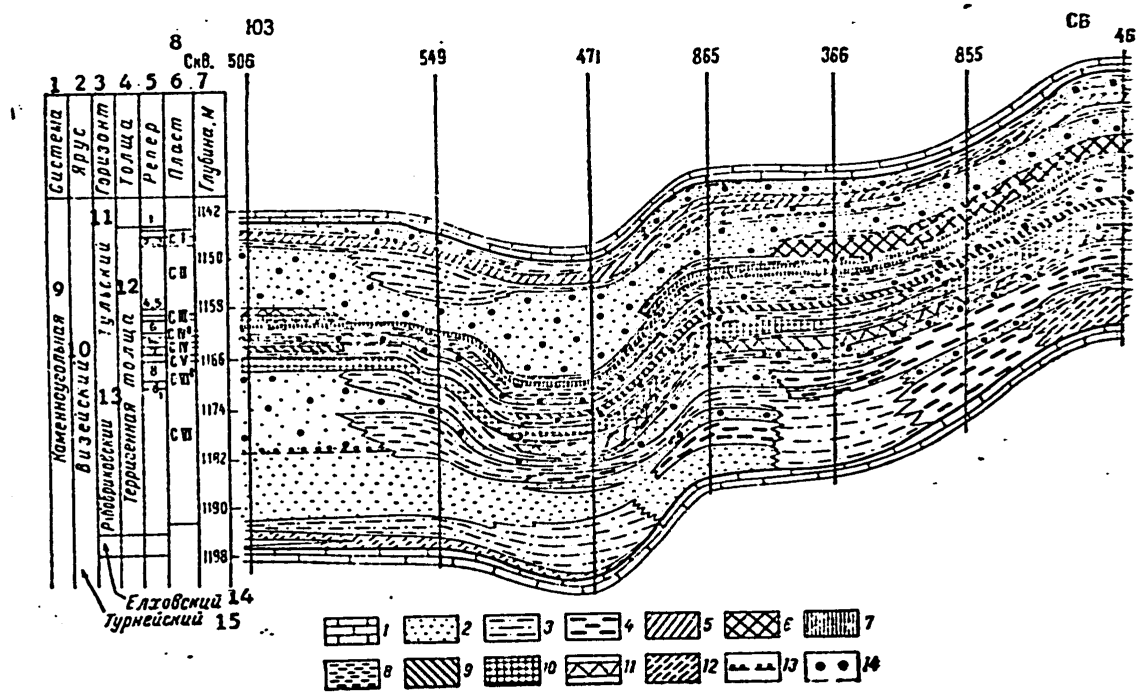


Figure 32. The Arlanskoye oil deposit. Geological profile along the line of wells 506-46 of the Arlanskaya area. 1 -- limestones; 2 -- sandstone collectors; 3 -- siltstone rocks; 4 -- coaly-clayey rocks; 5 -- clayey rocks -- reference marks 2, 3; 6 -- clayey rocks -- reference marks 4, 5; 7 -- clayey rocks -- reference mark 6; 8 -- clayey rocks -- reference mark 6; 9 -- clayey rocks -- reference mark 7; 10 -- clayey rocks -- reference mark 8; 11 -- clayey rocks -- reference mark 8; 12 -- clayey rocks -- reference mark "Yelkhovskiy"; 13 -- water-oil contact; 14 -- oil-saturated sandstones.

Key:

1 -- System	5 -- Reference mark	9 -- Carboniferous	13 -- Bobrikovskiy
2 -- Stage	6 -- Reservoir	10 -- Vizeyskiy	14 -- Yelkhovskiy
3 -- Horizon	7 -- Depth, m	11 -- Tul'skiy	15 -- Turneyskiy
4 -- Formation	8 -- Well	12 -- Terrigenous formation	

In the eastern half of the central part of the Arlanskaya area a fairly wide band of sharp fluctuation of thicknesses of reservoir C-II is traced (from zero to 8 m). Narrow bands of highly permeable traps are noted. On marginal sections and in the western half of the Arlanskaya area, zones of sandstones with a thickness of up to 3.6 m are widespread. It is observed that small lenses of dense rocks are confined to lines oriented in a northeast direction, transversely to the course of the Arlanskaya structure. On the Nikolo-Berezovskaya area, traps were encountered in its southern part. The rock thicknesses are 1 to 3 m, with maximum values of 7 m.

The absence in the section of reservoir C-II of layers sustained in thickness and area, in contrast with reservoir C-VI, creates the impression that the traps of the reservoir are homogeneous over the entire area. Detailed study of the sections shows that individual intervals of a thick reservoir have different permeability and in essence are individual layers. According to our data, in reservoir C-II on the Novokhazinskaya area, for example, four interstratifications are distinguished which are well comparable with individual interstratifications of the Arlanskaya oil-bearing area (Figures 33 & 34). On some sections those interstratifications are in turn also broken up, as a result of which an extremely heterogeneous thin-layer reservoir is observed.

At the Sauzbashevskoye deposit reservoir C-II, with a thickness of up to 5 m, is distributed mainly in the southeastern part of the area. The reservoir has a continuous lenticular structure. At the Cheral'skaya area the sandstones of reservoir C-II, which are sustained in thickness (4 to 6 m) and area, are confined to the central part of the structure. On the limbs of the structure the sandstones decrease in thickness, become clayey and are replaced by clayey siltstones. Reservoir C-II is more widespread on the Chetyrmanskaya and Kuzbayevskaya areas (up to 9 m).

Traps of reservoir C-I, with a thickness of up to 4 m, are encountered in the northern part of the Arlanskoye deposit. At the Sauzbashevskoye deposit reservoir C-I is observed in the form of two lenses--in the western part of the area with thicknesses of up to 1.8 m and in the southeast with up to 2.4 m.

The thickness of the upper member on the Arlanskaya area fluctuated from 8 to 20 m. A direct dependence is noted between the thickness of the member on the whole and of the traps in it. The thickness of the terrigenous part (in 80 percent of the wells), including reservoirs of sandstone, varies from 11 to 16 m. When the thickness of the member was below 11 m, traps were discovered in 6 percent of the wells.

Values of the arenosity coefficient of 20 to 40 percent predominate over a considerable portion of the area. Zones with values of the coefficient over 40 percent form a large band in the central part of the Arlanskaya area, oriented from north to south and connected mainly with the presence of at least 2 or 3 producing reservoirs. Large zones with arenosity coefficients of less than 20 percent are widespread in the west, north and east of the

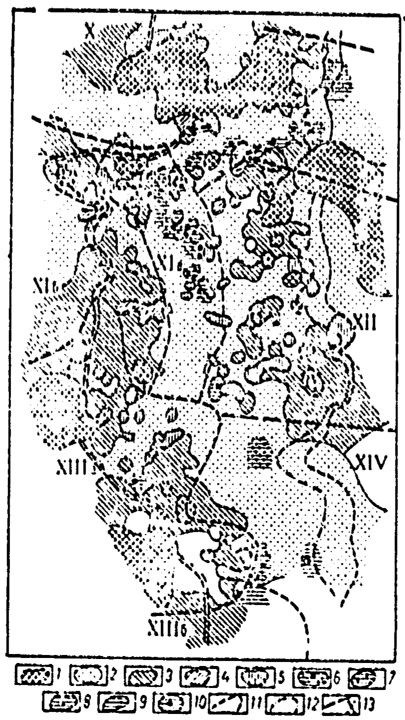


Figure 33. Diagram of the development of sections of reservoir C-II of the Novokhazinskaya area. 1 -- sections of replacement of traps by dense rocks; 2 -- sections where layers C-II_B and C-II_H converge; 3 -- sections where the traps consists only of the layer C-II_B; 4 -- sections where the trap consists only of layer C-II_H; 5 -- sections where the trap consists of layers C-II_B and C-II_H with interstratification of dense rock between them; 6 -- sections where the layers of traps C-II_B, C-II_H and C-II_{III} converge; 7 -- sections where the layers of traps C-II_H and C-II_{III} converge; 8 -- sections where layers C-II_H and C-II_{III} converge and layer C-II_B consists of a trap; 9 -- sections where the trap consists of layers C-II_B and C-II_{III}; 10 -- sections where the trap consists only of layer C-II_{III}; 11 -- external oil pool outline; 12 -- internal oil pool outline; 13 -- boundary and number of sections.

of the area and outline the sections with a complete absence of traps in the upper member.

The maximum value of the zonation coefficient (2.12) was noted in the extreme west in the region of the settlement of Saklovo. Reservoirs C-II and C-II and also C-I in part are widespread there (Table 4). The lowest mean values of the zonation coefficient (1.11-1.21) are characteristic of marginal sections of the area, where reservoir C-II is mainly distirbuted. Therefore in place of the coherence coefficient, the coefficient of consistency was determined separately for each reservoir for the individual sections (Table 4). The largest coefficient of consistency is characteristic of reservoir C-II, and the smallest values are noted for reservoirs C-I and C-III. Since reservoir C-III is insignificantly distributed on the area, its coefficient of consistency fluctuates very sharply (from zero to 0.80).

At the Andreyevskoye deposit that coefficient fluctuates from 0.05 in the east to 0.66 in the west of the area, which indicates a weak hydrodynamic connection of reservoirs C-I, C-III, C-IV and C-V.

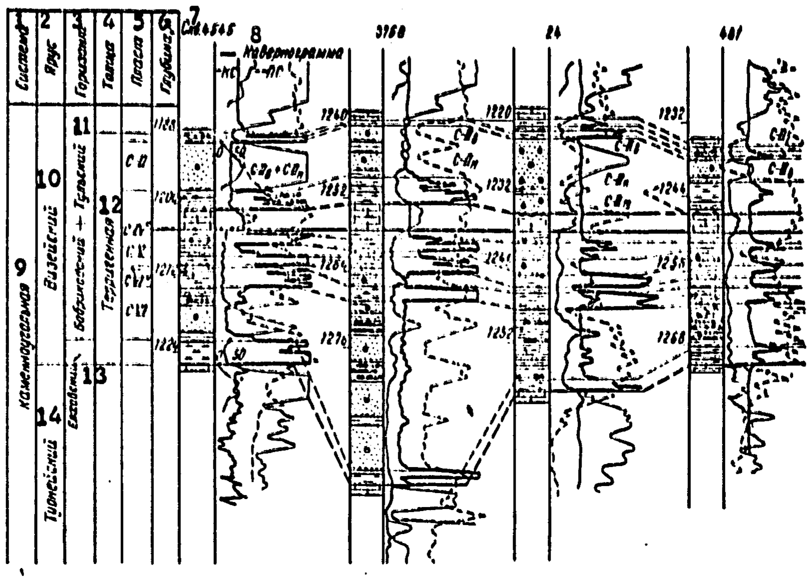


Figure 34. Principal types of sections of reservoir C-II of the Novokhazinskaya area.

1 -- System	8 -- Cavernogram
2 -- Stage	9 -- Carboniferous
3 -- Horizon	10 -- Vizeyskiy
4 -- Formation	11 -- Bobrikovskiy + Tul'skiy
5 -- Reservoir	12 -- Terrigenous
6 -- Depth, m	13 -- Yelkhovskiy
7 -- Well	14 -- Turneyskiy

At the Arlanskoye deposit the layers of terrigenous rocks in the lower Carboniferous were also encountered in the Aleksinskiy horizon. Sandy reservoirs were noted in the Aleksinskiy horizon in 25 percent of the wells of the deposit. The discovered zones of sandy traps consist of separate lenses, different in size and shape (Figures 35 and 36). The thickness of the sandstones reaches 14 m (Table 5).

Thicknesses of 2 to 8 m are encountered very often on the Nikolo-Berezovskaya area and thicknesses of 12 to 14 m are known in isolated cases on the Arlanskaya and Novokhazinskaya areas (Table 5). Thicknesses of up to 2 m predominate on all areas.

Table 4. Coefficients of heterogeneity of the upper member of sections of the Arlanskaya area

Участки 1	Выдержанность пластов 2			Расчлененность 3	Песчанистость 4
	С-I	С-II	С-III		
5 Ашитский	0,66	0,61	0,39	2,0	0,23
6 Нагаевский	0,26	0,90	0,07	1,32	0,26
7 Актанышбашевский	0,36	0,96	0,18	1,56	0,37
8 Сакловский	0,40	0,82	0,80	2,12	0,31
9 Арланский (V)	0,61	0,77	0,56	2,04	0,27
10 Арланский (VI)	0,51	0,82	0,12	1,64	0,31
11 Краевой	0,12	0,53	0,03	1,21	0,27
12 Уртаульский	0,05	0,56	0	1,11	0,23
13 Николо-Березовский (I)	0,14	0,96	0,30	1,36	0,29
14 Николо-Березовский (II)	0,40	0,61	0	1,31	0,27

Key:
1 -- Sections
2 -- Consistency of reservoirs
3 -- Zonation
4 -- Arenosity
5 -- Ashitskiy
6 -- Nagayevskiy
7 -- Aktanyshbashevskiy
8 -- Saklovskiy
9 -- Arlanskiy (V)
10 -- Arlanskiy (VI)
11 -- Krayevoy
12 -- Urtaul'skiy
13 -- Nikolo-Berezovskiy (I)
14 -- Nikolo-Berezovskiy (II)

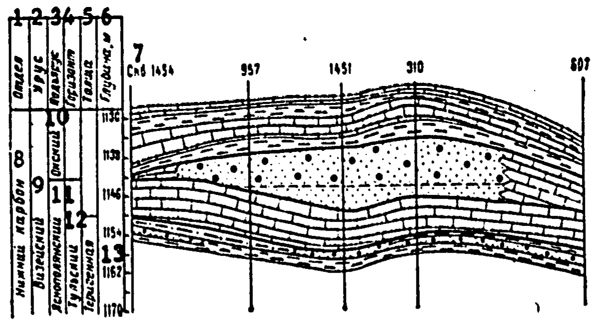


Figure 35. Geological profile along the line of wells 1454-607.

Key:
1 -- Series
2 -- Stage
3 -- Substage
4 -- Horizon
5 -- Formation
6 -- Depth, m
7 -- Well
8 -- Lower Carboniferous
9 -- Vizeyskiy
10 -- Okskiy
11 -- Yasnopolyanskiy
12 -- Tul'skiy
13 -- Terrigenous

Table 5. Distribution of thicknesses of traps by number of wells on the areas, %

1 Мощность, м	2 Площадь		
	3 Николо-Березовская	4 Аланская	5 Новохазинская
	6 Количество скважин		
0—2	46	68	72
2—4	11	12	17
4—6	20	6	4
6—8	16	6	3
8—10	4	4	3
10—12	2	3	1
12—14	1	1	—

Key: 1 -- Thickness, m
2 -- Area
3 -- Nikolo-Berezkovaya
4 -- Alanskaya
5 -- Novokhazinskaya
6 -- Number of wells

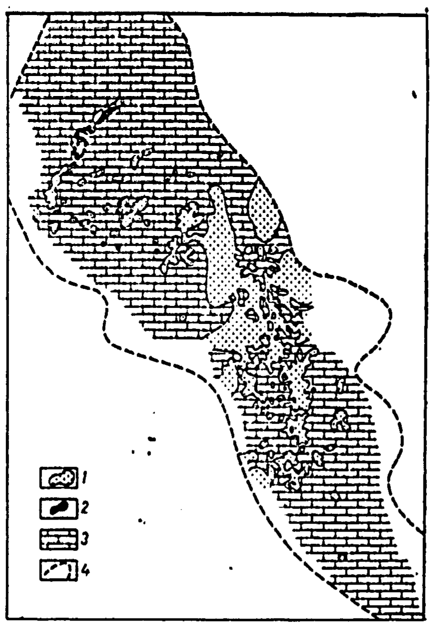


Figure 36. Diagram of the distribution of sandy traps of the Aleksinskiy horizon of the Alanskye oil deposit. 1 -- section of development of sandy traps; 2 -- oil pools; 3 -- zones of development of limestones in contact with sandstones; 4 -- provisional boundary of deposit.

Thus the terrigenous formation of the Lower Carboniferous of the Arlanskaya and other oil deposits of Bashkiriya is characterized by a very complex structure. Reservoir traps have a heterogeneous structure: in the vertical section several reservoirs and interstratifications are traced which differ considerably in their extent and trap properties (permeability, oil saturation, clayeyness, etc). On individual areas from six to eight producing reservoirs are distinguished in the vertical section, reservoirs which have independent importance. The main reservoirs C-VI and C-II have the largest thicknesses and are widespread on all the areas.

Traps of the remaining reservoirs of the terrigenous formation have small thicknesses and low collector properties. Often in very short distances they are replaced by dense siltstone rocks; the zones of development of traps rarely coincide in the plane.

The lenticular development of producing reservoirs and interstratifications of the terrigenous formation of the Lower Carboniferous (together with structural position) cause a complex position of the oil pool outlines of individual pools.

On the example of the Arlanskaya and adjacent areas, in studying the heterogeneity of the structure of sections of the terrigenous formation of the Lower Carboniferous, a direct dependence was found between the thickness of the lithological members (lower and upper) and the total thickness of the traps enclosed in them in the predominant range of thicknesses. No such dependence was detected for the middle member.

The average values of the coefficients obtained on the area are different: arenosity for the lower member is 0.49, for the middle is 0.21 and for the upper is 0.23; of zonation--1.92, 1.70 and 1.55 respectively; of coherence --0.32 (for the lower member). These parameters indicate that in the section of the terrigenous formation clayey varieties of rocks predominate, the producing sections are considerably broken up and the connection between the producing reservoirs is weak. In addition, the mean values obtained on different sections of the area for all the members fluctuate considerably (the arenosity coefficient by 2-2.2 times, the breakdown coefficient by 1.5-2 times, and the coherence coefficient by 3 times for the lower phase, and for individual reservoirs confined to the middle and upper members the consistency coefficient fluctuates by 6 and 3.6 times respectively).

Consequently the degree of heterogeneity of traps on the Arlanskaya area is exceptionally high. Maps of the percentage content of sandstones together with maps of types of sections of the reservoirs C-II and C-VI, and also maps of the development of the traps of reservoirs of the middle part combined in the plane, along with other data, serve as the principal starting geological material in the planning and analysis of a development. Those maps help to correctly solve questions connected with the disposition of planned operational and pressure wells, to select the variant of effect on the pool with consideration of the discovery of all reservoirs and interstratifications constituting the producing horizon and to designate the ways to regulate the development.

Characteristics of Carbonate Traps

The principal distinctive features of carbonate traps will be considered on the example of deposits of the Middle Carboniferous of northwestern Bashkiriya, which have a structure typical of the carbonates of Uralo-Povolzh'ye.

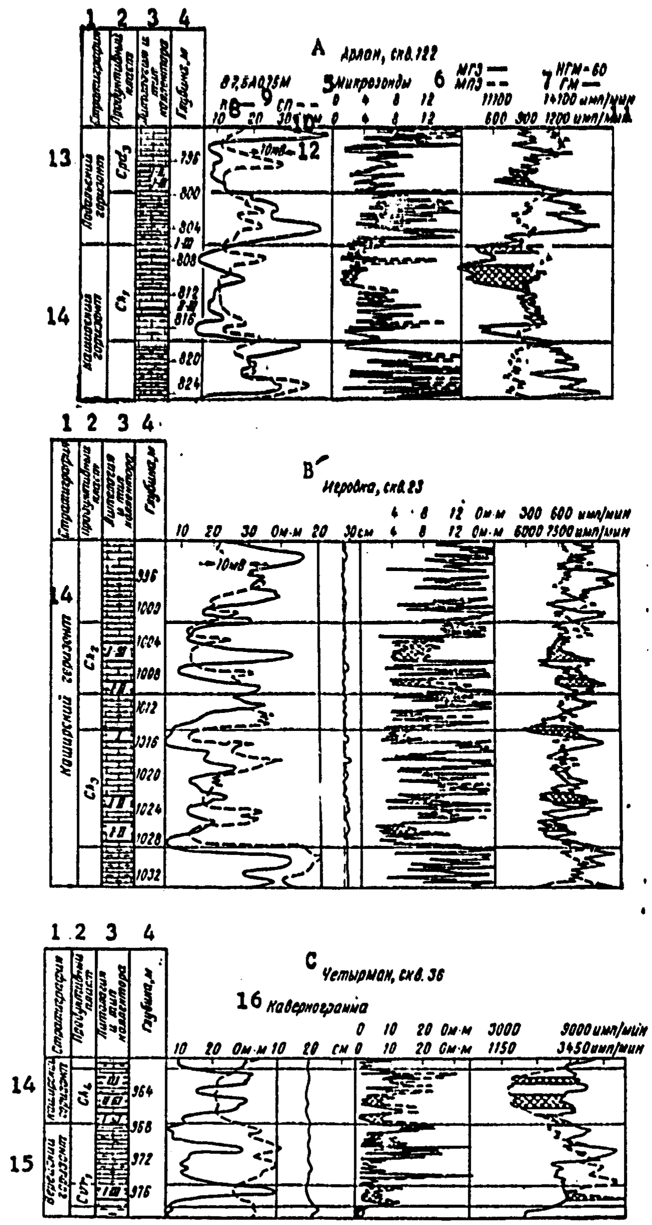
From the structure and dimensions of the void space three principal types of traps are usually distinguished: porous, fissured and porous-fissured. Each them is characterized by special principles of separation over an oil field geophysical unit. Many works containing both general and specific materials for individual deposits have been devoted to the question of separating layers of traps and estimating their trap properties by methods of oil field geophysics [2, 14, 19, 24, 29, etc]. That question has been worked out most completely of all for the ideal case of a thick, homogeneous, porous carbonate traps. Taken as the basis for the separation of layers of traps with a standard oil field geophysical method in that case are diagrams of neutron gamma-logging, microsondes, the gamma-method and PS [expansion unknown]. NGM [neutron-gamma-method] curves, which are in essence a function of the hydrogen content, characterize layers of porous traps by intermediate indications of I_{rel} within the range of 0.6 to 0.8. With microsondes those intervals are separated on the basis of the positive divergence in the indications of micropotential- and microgradient-sondes or low resistances on the microgradient-sonde curve ($< 10\rho_c$), minimal values on the GM curve and negative anomalies on the PS curve.

Presented on Figure 37 are examples illustrating distinctive features of the separation of porous traps on the basis of data of a standard oil field geophysical method with regard to wells of the Arlanskoye and Igrovskoye deposits.

Much more complicated is the separation of layer traps of the fissure and fissure-porous types. The difficulty in interpretation has, above all, two causes: the complex distribution of voids and their confinement to dense and clayey carbonate rock. Therefore the group of oil field geophysical investigations used at present does not always give definite characteristics for the establishment of the types of traps under consideration.

For the distinguishing and determination of secondary porosity* the method of complex interpretation of diagrams of electro- and radiometry has been

*By secondary porosity is understood the hollowness of fissures and caverns.


A Арлон, скв.122
5 Микрозонды
B
C Четырман, скв. 36
16 Кавернограмма
13
14
15
1 2 3 4

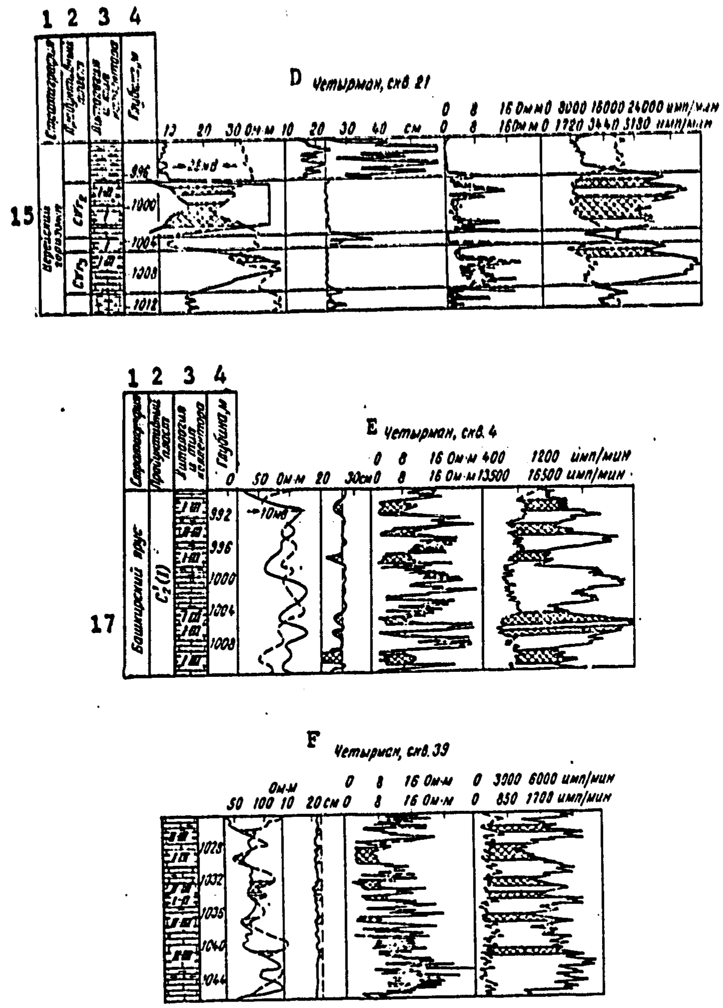


Figure 37. Separation of layers of traps of Middle Carboniferous deposits of northwestern Bashkiriya according to results of lithological-petrographic and oil field geophysical investigations. Types of traps; I - porous, II - fissure, III - porous-fissure. See key on page 61.

Figure 37, key:

1 -- Stratigraphy	A -- Arlan, well 122
2 -- Producing reservoir	B -- Igrovka, well 23
3 -- Lithology and trap type	C -- Chetyrman, well 36
4 -- Depth, m	D -- Chetyrman, well 21
5 -- Microsonde	E -- Chetyrman, well 4
6 -- MGZ and MPZ	F -- Chetyrman, well 33
7 -- NGM and GM	
8 -- KS	13 -- Podol'skiy horizon
9 -- SP	14 -- Kashirskiy horizon
10 -- ohm•m	15 -- Vereyskiy horizon
11 -- imp/min	16 -- Cavernogram
12 -- mV	17 -- Bashkirskiy stage

developed by A. M. Nechay [29] and widely introduced for the deposits of the Caucasus. In Middle Carboniferous deposits that method has not been used due to the considerable heterogeneity of carbonate deposits and the impossibility of determining ρ_p with sufficient precision by BKZ in reservoirs with a thickness of less than 2 m.

The authors recommend the separation of fissure and fissure-porous traps in accordance with the totality of the following characteristics: higher indications of the NGM diagrams (I_{rel} from 0.7 to 0.9); positive PS anomalies and high values of natural gamma-activity; medium ρ_k values; absence of increments on the microsondes.

Those features are also characteristic of dense carbonate rocks. In that case BKZ and BK curves can introduce some clarity. The value of ρ_p in a dense section determined with them will be considerably higher than in a reservoir with fissure and fissure-porous types of traps.

In principle, various methods of radiometry can be used to determine the porosity of porous carbonate rocks: the neutron gamma-method (NGM), the method of the density of thermal neutrons (NM_t), the method of the density of epithermal neutrons (NM_{et}), the gamma-gamma-method (GGM), the gamma-method (GM) and the tagged-liquid method (7, 14, etc].

In the carbonate traps of Bashkiriya the NGM and GM methods are mainly used in estimating the coefficient of porosity. For Kashiro-Podol'skoe deposits the effectiveness of NGM porosity determination has been evaluated. The value of the mean relative error proved to be 31.4 percent for the single reference horizon method and 16.2 percent for the method of two reference horizons [19].

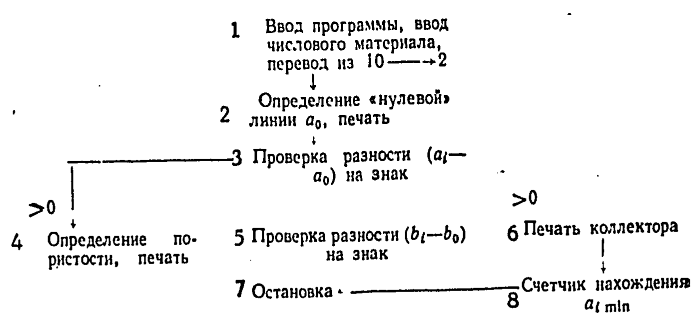
Besides manual interpretation of oil field geophysical investigations, computers can be used to separate porous traps and determine their porosity [3]. The successful solution of this question starts from the possibilities of using the basic principles of manual processing with the help of the computer.

In the manual separation of permeable layers the following principle is adopted: intervals having minimal and high NGM values for high GM values were considered a non-trap and intervals having mean indications on the NGM curve (I_{rel} from 0.6 to 0.8) were taken to be a trap. To establish a more or less distinct boundary between the low, medium and high NGM values, for further computer operations the definition of a "zero" line on the NGM curve was introduced, corresponding to the lower limit of porosity of the trap, that is, I_{rel} = 0.6 to 0.8.

To separate the GM indications into low, medium and high the medium line was taken, drawn parallel to the axis of depths (abscissas) with an ordinate equal to the minimum NGM indication against a trap with a very high porosity. In determining porosity by computer a graphic method was used (Figure 38) [3].

Then a combined program was compiled for separating traps and determining their porosity with the computer. The results were printed in the form of a lithological column in which traps and non-traps were distinguished, after which the porosities of the noted layers were printed. The following numeric material was referred to the main memory of the computer: the NGM indications on the axis of depths every 0.4 m in the interval in question and the GM indications in the same interval.

Block diagram of program



Key:
1 -- PROGRAM INPUT, DIGITAL DATA INPUT, DECIMAL-BINARY CONVERSION
2 -- DETERMINATION OF "ZERO" LINE α_0, PRINTING
3 -- CHECKING OF DIFFERENCE ($\alpha_i - \alpha_0$) FOR SIGN
4 -- DETERMINATION OF POROSITY, PRINTING
5 -- CHECKING OF DIFFERENCE ($b_i - b_0$) FOR SIGN
6 -- PRINTING OF COLLECTOR
7 -- REGISTER OF FINDING $\alpha_{i\,min}$
8 -- STOP

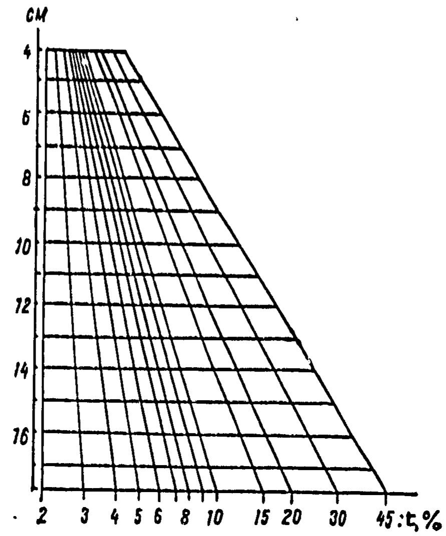


Figure 38. Nomogram for RK determination of porosity of carbonate deposits.

The data of Table 6 show that for more or less homogeneous rocks (for example, well 162, intervals 787.2-800 m, 808-810 m, 810.0-812.4 m, etc) the layers of traps and non-traps separated "manually" and by computer and the values of their porosity coincide in the main. In strongly heterogeneous layers consisting of frequent stratification of rocks of different lithological composition and trap properties, for example, in well 227 (interval 802-812 m), there are considerable divergences both in the separated thickness of the traps and in the value of their porosity. In those cases it is difficult to obtain a correct estimate of the results by either "manual" or computer processing.

Comparison of the porosity values obtained by the NGM with core data shows that errors are possible in both manual and computer data processing. As a result of analysis the authors concluded that it is inadvisable to use a computer to interpret carbonate reservoirs strongly heterogeneous in lithological composition and trap properties. In carbonate reservoirs of more or less homogeneous structure that method is applicable and gives useful results.

To study the trap characteristics of porous layers, along with the use of geophysical methods a detailed investigation was made of cores from producing reservoirs of the Middle Carboniferous of northwestern Bashkiriya.

Table 6. Comparison of the results of machine and "manual" processing of oil field geophysical diagrams of the Kashiro-Podol'skoye sediments of tht Arlanskoye deposit

	1 Ручная обработка			2 Машинная обработка		
3 Скважина	4 Интервал, м	5 Мощность, м	6 Пористость, %	4 Интервал, м	5 Мощность, м	6 Пористость, %
294	785,2—793,0	7,8	7 Неколлектор	785,2—793,6	8,4	Неколлектор
	793,0—795,0	2,0	11	793,6—795,0	1,4	14
	795,0—810,0	15,0	Неколлектор	795,0—802,4	7,4	Неколлектор
				802,4—810,4	8,0	15
	810,0—813,0	3	35	810,4—812,0	1,6	30
	813,0—822,0	9	Неколлектор	812,0—822,0	10	Неколлектор
188	779,6—792,0	12,4	Неколлектор	779,6—792,8	13,2	Неколлектор
	792,0—794,0	2	15	792,8—794,4	1,6	15
	794,0—800,0	6	Неколлектор	794,4—800,8	6,4	Неколлектор
	800,0—802,0	2	11	800,8—802,2	1,4	16
	802,0—805,0	3	Неколлектор	802,2—805,6	3,4	Неколлектор
	805,0—807,0	2	15	805,6—807,2	1,6	15
227	779,2—794,2	15	Неколлектор	779,2—794,2	15	Неколлектор
	794,2—795,0	0,8	11	794,2—795,4	1,2	14
	795,0—802,0	7	Неколлектор	795,4—802,0	6,6	Неколлектор
	802,0—812,0	10	21	802,0—803,4	1,4	8 Коллектор
				803,4—804,8	1,4	Неколлектор
				804,8—806,1	1,3	18
				806,1—806,8	0,7	Неколлектор
				806,8—809,0	2,2	25
				809,0—809,8	0,8	Неколлектор
				809,8—810,2	0,4	Коллектор
				810,2—810,6	0,4	Неколлектор
				810,6—811,6	1,0	Коллектор
	812,0—821,6	9,6	Неколлектор			
162	787,2—800,0	12,8	Неколлектор	787,2—800,0	12,8	Неколлектор
	800,0—802,0	2	12	800,0—801,2	1,2	15
	802,0—808,0	6	Неколлектор	801,2—808,0	6,8	Неколлектор
	808,0—810,0	2	13	808,0—809,6	1,6	15
	810,0—812,4	2,4	Неколлектор	809,6—813,2	3,6	Неколлектор
	812,4—827,2	12,8	»	814,8—827,0	12,2	»

Key: 1 -- Manual processing
2 -- Machine processing
3 -- Well
4 -- Interval, m
5 -- Thickness, m
6 -- Porosity, %
7 -- Non-collector
8 -- Collector

Producing reservoir C_2^1 (I) of the Bashkirskiy stage contains all three types of traps. The porous-fissure and porous types predominate and constitute 51 and 34 percent of the volume, and the share of the fissure type is 15 percent.

Porous traps are characteristic of biomorphous and dolomitic limestones. In biomorphous limestones the pores are confined to cavities in organic residues and to interorganogenous interstices of slitlike and irregular form. Pores are hollow and open, some are isolated, and others are connected by means of intergranular spaces. Pore dimensions vary from 0.015 to 1 mm, pores from 0.015 to 0.15 mm in size predominate (fine-pored), and pores partially or completely filled with oil, gypsum and more rarely calcite are encountered at times. In dolomitic limestones the pores usually are intergranular, often hollow or filled with oil, and their dimensions vary from 0.25 to 0.8 mm (medium-pored or more rarely coarse-pored).

Traps of the fissure type are encountered more rarely. They are confined mainly to detritus-slime linestones. On slides the fissured character of rocks is expressed by single fissures. The maximum size of their opening does not exceed 1-1.5 mm. Microfissures are divided into two types --tapering off and slightly tortuous. Fissures with an opening of 1 mm are usually clean, and fissures with an opening of 0.02-0.1 mm often reveal traces of the migration of oil and mineral solutions. Macrofissuring is observed at a number of areas of northwestern Bashkiriya. The presence of both vertical (secant) and horizontal fissures has been noted.

The special importance of fissues is that they, without increasing substantially the capacity of the traps, play a considerable role in increasing their permeability.

Pourous-fissure traps are encountered very often. They are characteristic of organogenous-detrital, cloddy and partially biomorphous limestones.

In organogenous-detrital and biomorphous limestones the pores are confined to the organic residues and to the cementing material. Their form is irregular and their dimensions are from 0.015 to 0.25 mm (fine-pored). The size of the opening of microfissures is mainly from 0.05 to 0.1 mm. Fissures serve as connecting channels between separate pores (connective); tapering out pores are encountered more rarely. In cloddy limestones the pores are confined to the intercluster residues and more rarely to cavities in the organic residues, and their dimensions vary from 0.015 to 0.5 mm. The form of the pores is varied, often extended. Microfissuring is weakly developed and microfissures are partially filled with calcite, more often with dolomite. Hollow open microfissures are encountered more rarely. In samples of rocks at the Igrovskaya and Karacha-Yelginskaya areas, single open cavities with dimensions of 2 to 4 mm have been encountered in cloddy limestones.

Of secondary processes, calcitization, sulfatization and dolomitization are widespread; pyritization and silicification of rocks are not considerable. Dolomitization usually contributes to improvement of collector properties, but other secondary processes considerably reduce the volume of the pore space of rocks.

A rock trap of the porous or porous-fissure type in a producing reservoir lies, not in monolithic layers, but often in a thin alternation with dense rock (from 0.01 to 2 m). Traps of the fissure type are more often confined to layers of dense rock. The trap properties of rocks fluctuate within broad limits: the porosity from 1 to 21 percent and the permeability from zero to 45 mD.

To divide rocks into the producing and nonproducing, data obtained in the study of the trap properties of rocks to determine the lower limit of porosity were processed. Used in the systematization were the recommendations of M. N. Kochetov [21], the basis of which is the principle of correlation analysis. It is assumed provisionally that traps with a permeability greater than 1 mD are industrially productive. Figure 39 presents a graph of the correlation between porosity and permeability which shows that samples with a permeability of less than 1 mD have a porosity below 9 percent. The indicated amount of porosity can be taken provisionally as the lower limit of porosity of traps of a producing reservoir. Samples with less porosity should be classed as non-traps.

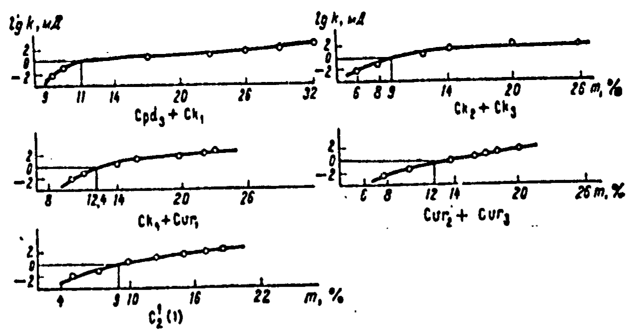


Figure 39. Correlation between permeability and porosity for producing reservoirs of the Middle Carboniferous deposits of northwestern Bashkiriya.

The correlation between permeability ($\bar{k}$) and porosity ($\bar{m}$) is established with the procedure described in the work of Ye. I. Semin [34]. The mean value of the coefficient of proosity for the traps of producing reservoir C_2^1(I) is 13.6 percent at a standard deviation $\sigma_m = 0.15$, and the permeability is correspondingly 45 mD at $\sigma_k = 0.07$.

It has been established that in the interval of mean values of porosity the permeability has the following dependence, $\lg \bar{k} = 0.08\, m + 0.563$. Correspondingly the porosity $\bar{m} = 5.3 \lg k + 4.83$, where $\bar{k}$ is the permeability in mD and m is the porosity in percent. The cited formulas can be used to estimate the lacking characteristics of trap properties of producing reservoirs when the analysis of samples is incomplete.

The study of the trap properties of producing reservoir C_2^1 (I) was carried out, besides with laboratory investigations, on NGM diagrams processed "manually" and by computer with the above-described methods. The determination of porosity in 108 wells showed good agreement with the core data. The mean porosity is 13.6 percent from 147 core determinations and 14.2 percent according to the geophysical data.

In the course of practical work with NGM diagrams, during their correlation with the given value, it was found that the criterion for relating layers to traps according to the NGM is the relative parameter I_{rel} in a value lower than 0.7. Corresponding to those intervals are the minimum GM indications, negative PS indications and positive increments on the MZ curves. Those features characterize the porous and pore-fissure types of traps.

The presence of the fissure type of traps was established in the same group of investigations but with a somewhat different characterization. Whereas the fissure type according to data of lithological and petrographic investigations is in the main confined to layers with a denser variety of rocks, the intervals with the fissure type of trap register NGM curves with a value of the parameter I_{rel} of 0.7 to 0.9, mean values of the apparent resistances and an absence of increments on the microsondes. In those cases the indications of the PS curves are positive and the GM indications are increased.

It must be taken into consideration that in sections of reservoir C_2^1 (I) a fine stratification of rock traps and dense varieties with ambiguous logging characteristics is encountered in many wells.

In the case of predominance of a trap over dense rock in the interval of thickness greater than 0.5 m, the standard set of oil field geophysical investigations registers the given interval as a trap. If single thin layers of traps are bedded among dense rocks, the same set is designated as dense rock. Examples of the separation of traps of the three types in a section of producing reservoir C_2^1 (I) are presented on Figure 37.

In producing reservoirs Cvr_2 and Cvr_3 of the Vereyskiy horizon three types of traps also are encountered: the porous makes up 56 percent of the volume of the traps, the porous-fissure 40 percent and the fissure type 4 percent.

Traps of the porous type are characteristic of biomorphous, oolitic, organogenous-detrital limestones, limy sandstones and dolomites. The pores are confined to the voids in organic residues and to interorganogenous and intergranular spaces. Some hollow pores are isolated, others are connected directly with the intergranular spaces, and pores are encountered that are filled with oil, calcite and gypsum. The pore dimensions vary from 0.015 to 2 mm or more. Medium-pored varieties of rocks with a diameter of 0.25 to 0.5 mm are widespread in that reservoir.

Traps of the fissure type are not widespread. They have been encountered in individual slides of detritus-slime limestones. Microfissures are slightly tortuous, with an opening of up to 0.02 mm.

Traps of the porous-fissure type are characteristic of organogenous-detrital, biomorphous and coagulated limestones. The pores are confined to the intercoagulate sections and voids in the organic residues and to the cementing material. The walls of the pores are slightly tortuous, of slit-like and irregular form, with dimensions of 0.01 to 0.6 mm, and fine-pored walls predominate. Serving as the connective channels between pores are microfissures up to 0.08 mm in size, and tapering out fissures are encountered more rarely.

The trap properties of the characterized rocks are considerably reduced because of the development of secondary processes -- calcitization, sulfatization, silicification and pyritization. The process of dolomitization, contributing mainly to increase of the volume of the pore space, is rarely manifested.

For reservoirs Cvr_2 and Cvr_3 the maximum porosity is 24 percent and the maximum permeability is 485 mD. The largest percent of permeable samples is limited to the range of porosity values from zero to 12 percent (Figure 39). The lower limit of the porosity is 12 percent. When the porosity is greater, increase of the humber of impermeable samples of the core is designated.

The conducted analysis shows a fairly close connection between the porosity and permeability (the correlation coefficient is 0.89), on the whole characterizing the porous type of traps of reservoirs Cvr_2 and Cvr_3.

The mean values of the porosity and permeability for the rock traps of producing reservoirs Cvr_2 and Cvr_3 are higher than those of C_2^1 (I). The porosity coefficient of the rock traps of producing reservoirs is 18.4 percent at a standard deviation σ_m of 0.3. The corresponding permeability coefficient is 75 mD at $\sigma_k = 1$.

The equations of the curves determining the mean values of the porosity and permeability for producing reservoirs are: $\bar{m} = 4 \lg k + 10.6$; $\lg k = 0.04\, m + 1.9$.

To separate layers of traps we recommend taking as a basis MZ diagrams since NGM and GM indications are distorted by the presence of a large amount of terrigenous material, due to which it is necessary to introduce corresponding corrections when they are used (Figure 37).

The carbonate rocks of producing reservoir Cvr_1 contain two types of traps: porous and porous-fissure.

The traps of the porous type are connected mainly with bimorophous and organogenous-detrital limestones. The pores are confined to the intercoagulate sections, the voids in the organic residues and the cementing material; the pores are open and their dimensions are from 0.01 to 0.2 mm.

Traps of the porous-fissure type are characteristic of all varieties of carbonate rocks of the reservoir Cvr_1. The pores are confined to the voids in organic residues, interorganogenous and intergranular spaces. Fine-pored varieties with pore dimensions of 0.01 to 0.4 mm predominate. Microfissures serve as the connective channels between pores. Of secondary processes, sulfatization and calcitization are widespread.

In the producing reservoir Ck_4 of the Kashirskiy horizon two types of traps are encountered: porous and porous-fissure.

Traps of the porous type are connected with bimorphous, organogenous detrital and dolomitic limestones. The pores are confined to organic residues, the cementing material and intergranular spaces; their dimensions are from 0.03 to 1 mm, and the medium-pored predominate with regard to pore dimensions.

Traps of the porous-fissure type are characteristic of the same rock varieties. The pores are confined to voids in the organic residues and to the cementing material; their form is irregular and they have dimensions of 0.16 to 1.4 mm. The pores are often connected by narrow and tortuous channels. In the dolomitic variety the pore space is of the intergranular type and is mainly of round form, with pore dimensions of 0.05 to 0.2 mm.

Of secondary processes, dolomitization and sulfatization are fairly strongly developed. The latter considerably reduces the trap properties of the rocks.

The porosity of productive reservoirs Ck_4 and Cvr_1, which are similar in their lithological and petrographic composition and are of the trap type, varies from zero to 25.1 percent. Their permeability reaches 780 mD. The lower limit of porosity is 12.4 percent (Figure 39).

The mean value of the porosity coefficient for the rock traps of producing reservoirs is 19 percent at a standard deviation σ_k of 0.4. The mean values of the porosity and permeability can be determined with the equations: $\lg \bar{k} = 0.091\,\bar{m} + 0.117$; $m = 4.7 \lg k + 11.42$.

The layers of traps in producing reservoirs Ck_4 and Cvr_1 are fairly clearly distinguished in logging investigations (Figure 37). They are often noted from low NGM indications (I_{rel} below 0.7 according to a limit of porosity of 12 percent), reduced indications of the apparent resistances, positive microsonde increments and reduced indications of the GM values and negative PS anomalies, which indicates an absence in nature of considerable admixtures of clayey material. The layers of dense rocks are marked by higher indications of the apparent resistances, and their I_{rel} values on the NGM curve above 0.7.

Producing reservoirs Ck_2 and Ck_3 contain all three types of collectors.

Traps of the porous type are characteristic of dolomites and more rarely of limy dolomites. The pores are confined mainly to the intergranular spaces, their dimensions are from 0.01 to 0.6 mm, more often they are isolated but those connected by means of intergranular spaces are also encountered.

Traps of the fissure type are observed in both limy dolomites and in organogenous-fragmentary dolomites. The pores are of the intergranular type, usually open, at times connected by fissures (0.02-0.06 mm). They are confined to the organic residues and the pore dimensions are from 0.02 to 0.8 m. Of secondary processes, sulfatization and calcitization, which lower the collector properties of rocks, are widespread.

The maximum amount of porosity is 31 percent and that of permeability is 230 mD. The largest quantity of impermeable samples is encountered in the porosity range from zero to 9 percent. The curve (Figure 39) characterizing the regular connection between the porosity and permeability values registers the presence of a low limit of porosity at the point corresponding to a value of 9 percent.

The mean porosity is 15 percent at a standard deviation σ_m of 1, and the permeability is 47 mD at $\sigma_k = 0.03$. The mean values of the porosity and permeability of the rock traps of producing reservoirs can be determined with the equations: $\bar{m} = 5 \lg \bar{k} + 6.64$; $\lg k = 0.08\ m + 0.47$.

In the separation of layers of traps in producing reservoirs Ck_2 and Ck_3 one should be oriented mainly toward microsonde diagrams, as the encountered thin layers (up to 0.5 m) of traps are bedded among dense fairly thick rocks and do not give a clearly expressed differentiation on the NGM and GM curves.

In the deposits of the producing reservoir Sk_1 of the Kashirskiy horizon, all three types of traps have been encountered. Traps of the porous-fissure type predominate (65 percent of the total volume of the collectors), the porous amount to 20 percent and the fissure type amount to a total of 15 percent.

Traps of the porous type were encountered in dolomites, the biomorphous and in fine-grained limestones. The pores, of mainly circular form, occupy the intergranular spaces and have dimensions of 0.05 mm. Connection of the pores is assured by thin gaps between adjacent grains.

The pores in biomorphous limestones penetrate the rock irregularly and are confined to the interorganogenous and intra-organogenous spaces. Their dimensions are 0.3 mm on the average.

Traps of the fissure type were encountered in fine-grained dolomites and micro-grained limestones. The fissures went in various directions: they were vertical, steeply dipping, diagonal and horizontal. Many of them are grouped in systems--open fissures and mineral (sulfate and bituminous). Open fissures are developed sporadically, in isolated cases forming independent systems. Mineral fissures taper out in short distances.

The fissure type of traps of reservoir Ck_1 is encountered together with the porous.

Traps of the porous-fissure type are encountered in all the lithological varieties of the rocks. The pores in the rocks usually are distributed irregularly, and their form is from slitlike to circular, at times almost spherical. A considerable portion of the pores is developed on account of the leaching of organic residues. The pore dimenstions are from 0.02 to 3 mm.

Side by side with effective microfissures, mineral fissures are widespread in the dolomites and limy dolomites.

Fissures characterized by different form and non-identical dimensions of the median sections (1-5 mm) are widespread in the structure of the void space. In the rock they have a chaotic orientation, as a rule. Among the cavities both communicating and isolated cavities are encountered in different ratios.

Of secondary processes, sulfatization, silicification, calcitization and to a lesser degree secondary dolomitization are strongly developed.

Layers of traps of all three types are distinctly separated with the oil field geophysical data; they correspond to lower indications of the apparent resistances and positive increments on microsonde diagrams, and also negative amplitudes on the PS curve and lower indications on the NGM and GM curves (Figure 37).

In the producing reservoir Cpd_3 of the Podol'skiy horizon, traps of the porous-fissure type predominate.

Traps of the porous type are encountered in coagulate, cloddy and biomorphous limestones. The pores are confined to the interorganogenous and intraorganogenous spaces. In form they usually are irregular, more often circular, with dimensions of up to 0.3 mm. In most cases the pores do not communicate with one another. But sometimes communication is accomplished by means of narrow interorganogenous gaps.

Traps of the fissure type are confined to the fine-grained limestones, dolomites and sulfate dolomites. They have limited development. Open fissures have been noted. The maximum parameters are: $B = 0.06$ mm, $m_{tr} = 1.4\%$ and $T = 440$ tr/m. The mean parameters of bituminous fissures are:

$B = 0.05$ mm, $\bar{m}_{tr} = 0.11\%$ and $T = 68$ to 77 tr/m. Mineral fissures are poorly developed and their dimensions are very low.

Traps of the porous-fissure type have been encountered in all the enumerated varieties of rocks. Pores are confined to organogenous, intergranular and interorganogenous spaces; they are slitlike and circular in form. Pore dimensions vary from 0.01 to 2 mm, with mean dimensions of 0.025 to 0.5 mm. Pores are connected by micro fissures which have openings that reach 0.08 mm. Of secondary processes, sulfatization, silicification and dolomitization are developed.

The trap properties of rocks fluctuate in broad ranges: porosity from 1 to 37 percent and permeability from zero to 890 mD. The values of the impermeable samples were limited to the porosity range of 1-11 percent. The graph of the dependence between porosity and permeability (Figure 39) shows that samples with a permeability of less than 1 mD have a porosity of less than 11 percent. That value is taken as the lower limit of porosity of collectors.

The mean value of the porosity coefficient for rock traps of the producing reservoirs Cpd_3 and Ck_1 is 23 percent at a standard deviation σ_m of 1.64. The corresponding value of the permeability is 48 mD at $\sigma_k = 0.14$.

It has been established that in the interval of mean values of the porosity the permeability has the following dependence: $\lg k = 0.04\ m + 0.761$; the porosity is $\bar{m} = 10 \lg k + 6.19$.

Figure 37 presents an example of the separation of layers of traps in producing reservoir Cpd_3 obtained from oil field geophysical data.

Thus in the section of the Middle Carboniferous deposits of northwestern Bashkiriya three types of traps are encountered: porous, porous-fissure and fissure. In the deposits of producing reservoir C_2^1 (I) of the Upper Bashkirskiy substage all three types of traps were encountered, but traps of the porous-fissure type predominate. In producing reservoirs of the Vereyskiy horizon Cvr_1, Cvr_2 and Cvr_3, porous predominate, more rarely, porous-fissure and still more rarely, the fissure type of traps. In producing reservoirs of the Kashirskiy horizon Ck_1, Ck_2, Ck_3 and Ck_4, and also in producing reservoir Cpd_2 of the Podol'skiy horizon, the principal types of traps are the porous-fissure and the porous, and fissure traps are rarely encountered. Thus the porous type of traps predominates in the Middle Carboniferous deposits.

The trap properties of producing reservoirs fluctuate in wide ranges. Permeability values vary from zero to 890 mD and porosity reaches 37 percent. It is evident from Table 7 that producing reservoirs $Cpd_3 + Ck_1$ and $Cvr_2 + Ck_3$ have better trap properties, and reservoirs $Ck_2 + Ck_3$, $Ck_1 + Cvr_1$ and C_2^1 (I) have worse.

Table 7. Numerical characteristics of carbonate collectors of the Middle Carboniferous deposits of northwestern Bashkiriya

1 Продуктивные пласты	2 Количество определений	3 Максимальная пористость, %	4 Максимальная проницаемость, мД	5 Нижний предел пористости, %	6 Стандартное отклонение		7 $m_{ср}$, %	8 $k_{ср}$, мД	9 Формулы характеристики
					σ_m	σ_k			
$Cpd_3 + Ск_1$	983	37	890	11	1,64	0,14	23	48	$\overline{m} = 10 \lg k + 6,19$ $\lg k = 0,04\ m + 0,761$
$Ск_2 + Ск_3$	324	31	230	9	1	0,03	15	47	$\overline{m} = 5 \lg k + 6,64$ $\lg k = 0,08\ m + 0,47$
$Ск_4 + Cvr_1$	795	25	780	12,4	0,4	0,4	19	41	$\overline{m} = 4,7 \lg k + 11,42$ $\lg k = 0,091\ m + 0,117$
$Cvr_2 + Cvr_3$	946	25	485	12	0,3	1	18,4	75	$\overline{m} = 4 \lg k + 10,9$ $\lg k = 0,04\ m + 1,138$
C_2^1 (I)	447	21	450	9	0,15	0,07	13,6	45	$\overline{m} = 5,3 \lg k + 4,83$ $\lg k - 0,08\ m + 0,563$

Key:
1 -- Producing reservoirs
2 -- Number of determinations
3 -- Maximum porosity, %
4 -- Maximum permeability, mD
5 -- Lower limit of porosity, %
6 -- Standard deviation
7 -- m_{av}, %
8 -- k_{av}, mD
9 -- formulas of characteristics

Regularities in the Distribution of Carbonate Traps and Their Heterogeneity

A special feature of producing carbonate reservoirs is their considerable heterogeneity, caused mainly by variation of the lithological-facial and trap characteristics. Heterogeneity of producing reservoirs over a section is expressed most often in a complex alternation of layers of dense rock and rock traps. Heterogeneity over the area is registered by change of the lithological-facial and collector properties, and also by considerable fluctuations of the thickness of traps.

Taken as the principal parameter in the study of the heterogeneity of producing reservoirs was the effective thickness of the layers of traps, determined from geological and geophysical data. To determine the quantitative characteristics of the heterogeneity of the studied reservoirs the following parameters were calculated:

1) the breakdown coefficient, which shows the ratio of the number of layers of traps in all wells to the number of wells

$$k_р = \frac{n_к}{n_с};$$

2) the coefficient of "granularity" (analogous to the coefficient of arenosity), that is, the ratio of the total thickness of the layers of traps to the total thickness of the reservoir for all wells

$$k_{гр} = \frac{\Sigma H_к}{\Sigma H_{общ}};$$

3) the coefficient of entropy, determined with the function

$$H_r = \frac{\sum_{i=1}^{H} P_i \lg P_i}{\lg N},$$

where P_i is the frequency with which layers of traps with a certain thickness are encountered.

Studies of distinctive features of the structure of producing reservoirs with the use of the cited coefficients and the regularity of the distribution of the traps in them are being made on the Middle Carboniferous deposits of northwestern Bashkiriya.

Producing reservoir C_2^1 (I) lies in the upper part of the Upper Bashkirskiy substage. It is regionally covered by a reservoir of limy argillites and marls lying mainly at the base of the Vereyskiy horizon. The thickness of those rocks is not identical: in the western part of the region studied it is small (2 Or 3 m) and in the east it reaches 6 to 8 m. The total thickness of producing reservoir C_2^1 (I) varies from 20 to 26 m.

According to core and especially to field geophysical data the reservoir under consideration is not homogeneous, and in its section a number of layers of traps are traced which alternate with layers of dense rocks. On the whole the section of a producing reservoir, starting from the heterogeneity of its structure, can be provisionally divided into three interstratifications: an upper, middle and lower.

The upper, with a thickness of 6 m, consists in the roof part of a layer of dense pelitomorphous limestone. The limestones underlying that layer have good trap properties. They lie in alternation with dense rocks. The number of layers of traps does not exceed four (in the Igrovskaya group of deposits) and they all are correlated well over the area. Westward (the Arlanskoye deposit) the number of layers decreases and does not exceed two. The total thickness of the traps varies from zero to 3.5 m.

The structure of the middle interstratification, with a thickness of up to 7 m, is somewhat similar to that of the upper but has its own distinctive features. The layers of traps of the middle interstratification of a producing reservoir are more sustained in thickness and in area of distribution. The total thickness of the layers of traps does not exceed 3 m and a number of the vary from 1 to 3.

The lower interstratification, with a thickness of 10 m, differs from the middle and upper. A three-meter thick layer of slightly permeable rock is traced in its upper part, and lower-lying layers of traps often have a lenticular structure.

In connection with that the number of layers of traps varies sharply and without any sort of regularity over the area even in short distances. There are from 1 to 7 layers and their total thickness is from 0.5 to 6 m.

The dense rocks covering each of the separated interstratifications evidently are not isolating covers for them, since fissuring is widespread in them, and thickness which is not constant and mainly very small (0.5 to 2 m). On the whole, over the entire producing reservoir no dependence is observed between the number of layers of traps and their total thickness. Their largest total thickness is 12.5 m. Complete replacement over the section was not noted.

The breakdown coefficient is 6.6 for the Igrovskaya group of deposits, 5.4 for the Dyurtyulinskaya and 4.7 for the Arlanskaya. Comparison of the degree of breakdown of producing reservoir C_2^1 (I) with regard to those groups of deposits shows that the highest breakdown occurs in the Igrovskaya group of deposits (Figures 40 & 41).

Layers of traps of reservoir C_2^1 (I) are distributed everywhere on the studied territory. Their total thickness and share of participation in the total volume of reservoir rocks are not the same, however, and vary in a wide range. That change is very graphically registered by the coefficient of granularity (k_{gr}). Three zones of development of traps are distinguished in the territory under consideration on the basis of the value of that coefficient.

Zone I embraces the northeastern part of the territory under consideration (Tatyshly, Igrovka and Kuzbayevo) and is characterized by very great development of traps (a coefficient of granularity of over 0.2). West of it (Arlan, Nikolo-Berezovka, Dyurtyuli, etc) zone II is distinguished, within which a reduction of the total thickness of the layers of traps is established (k_{av} from 0.1 to 0.2). Zone III (Or'yebash-Cheraul, etc) is characterized by exceptionally dense clayey carbonate rocks; the layers of traps are rare there and lie in the form of lenses of small thickness and extent (k_{gr} smaller than 0.1).

Heterogeneity in a reservoir as a function of the thickness and number of layers of traps has been studied using the coefficient of entropy. According to calculations on the map of the Igrovskaya group of deposits the traps have been provisionally combined into three groups on the basis of the coefficient of entropy: group I--traps with the most homogeneous structure (H_r from zero to 0.3); group II--with a less homogeneous structure (H_r from 0.3 to 0.6); group III--with an extremely heterogeneous structure (H_r from 0.6 to 1).

It follows from examination of maps of the structure of traps of producing reservoir C_2^1 (I) at the Igrovskoye, Chetyrmanskoye and Kuzbayevskoye deposits that the degree of heterogeneity in the structure of the layers of traps does not depend on their total thickness. Heterogeneity of group II predominates at all three deposits.

In comparing the values of the coefficient of entropy with the structural plan of the roof of producing reservoir C_2^1 (I) it was found that the layers of traps of the vault parts of upthrusts have a more homogeneous structure.

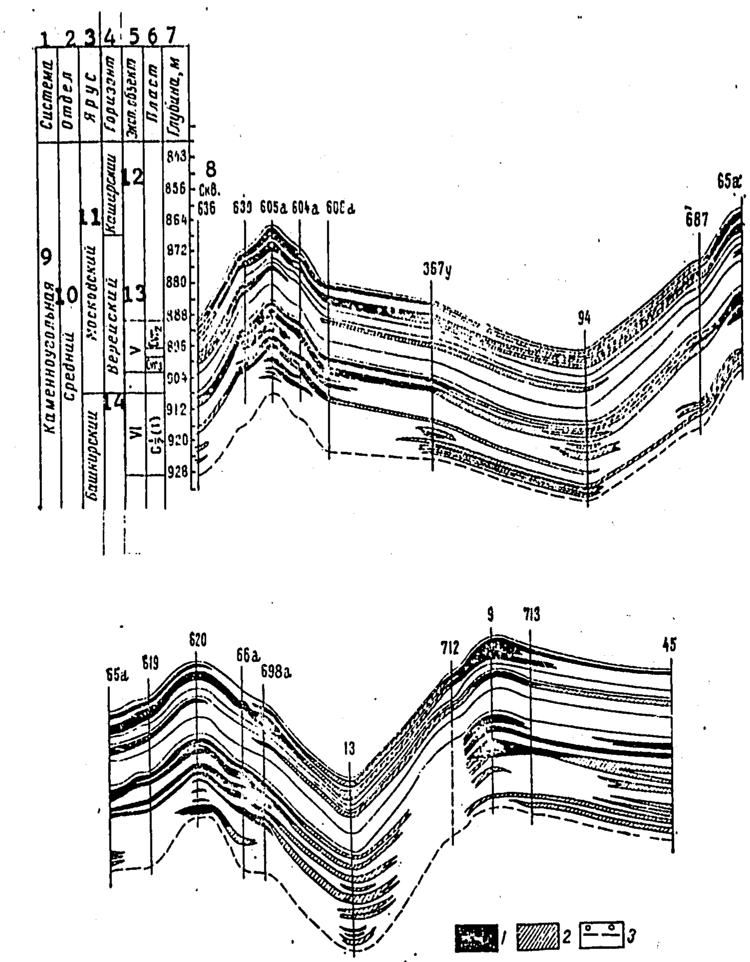


Figure 40. Schematic geological profile of the Middle Carboniferous deposits of the Igrovskoye deposit. Layers of traps: 1 - oil-bearing; 2 - water-bearing; 3 - water-oil contact.

Key:

1 -- System	8 -- Well
2 -- Series	9 -- Carboniferous
3 -- Stage	10 -- Middle
4 -- Horizon	11 -- Moskovskiy
5 -- Operated object	12 -- Kashirskiy
6 -- Reservoir	13 -- Vereyskiy
7 -- Depth, m	14 -- Bashkirskiy

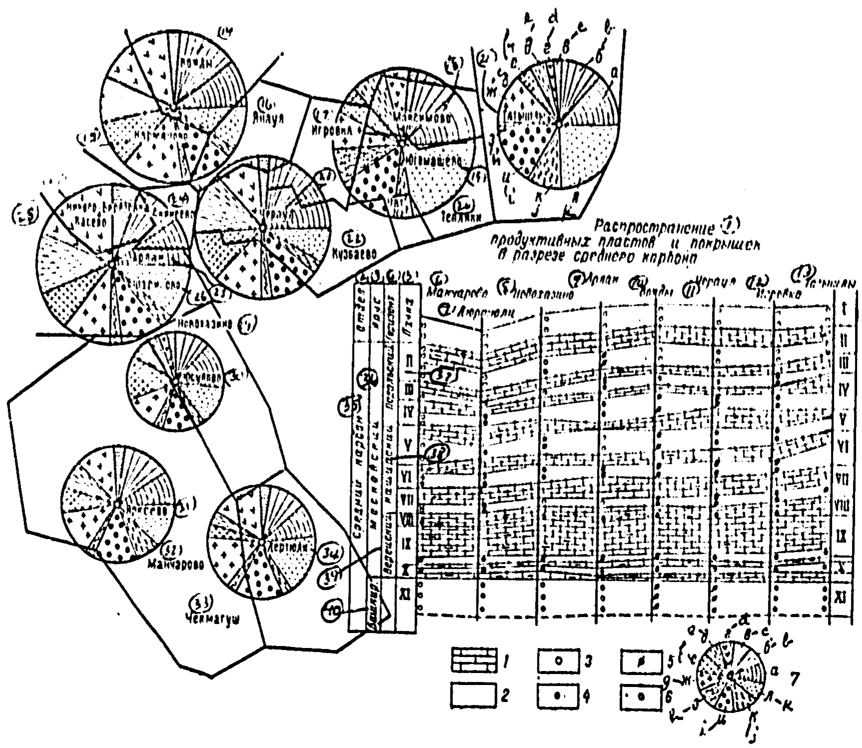


Figure 41. Distribution of traps in the section of the Middle Carboniferous of northwestern Bashkiriya.

1 -- reservoir covers and dense reservoirs
2 -- producing reservoirs
3 -- oil-bearing reservoirs
4 -- water-bearing reservoirs
5 -- reservoirs assumed to be oil-bearing
6 -- relatively impermeable reservoirs
7 -- diagram reflecting the percentage of traps of a specific producing reservoir from the total thickness of traps of the Middle Carboniferous

a -- CPd_1	e -- Ck_2	i -- Cvr_2
b -- Cpd_2	f -- Ck_3	j -- Cvr_3
c -- Cpd_3	g -- Ck_4	k -- C_2^1 (I)
d -- Ck_1	h -- Cvr_1	

8 -- provisional boundaries of sections
(Keying continued on next page)

1 -- Distribution of producing reservoirs and covers in the section of the Middle Carboniferous
2 -- Series
3 -- Stage
4 -- Horizon
5 -- Member
6 -- Mancharovo
7 -- Dyurtyuli
8 -- Novokhazino
9 -- Arlan
10 -- Voyady
11 -- Cheraul
12 -- Igrovka
13 -- Tatyshly
14 -- Voyady
15 -- Karmanovo
16 -- Yanaul
17 -- Igrovka
18 -- Maksimovo
19 -- Yugomashevo
20 -- Telyaki
21 -- Tatyshli
22 -- Kuzbayevo
23 -- Cheraul
24 -- Akineyevo
25 -- Arlan
26 -- Sharipovo
27 -- Nikolo-Berezovka
28 -- Kasevo
29 -- Novokhazino
30 -- Yusupovo
31 -- Yarkeyevo
32 -- Mancharovo
33 -- Chekmagush
34 -- Dertyuli
35 -- Middle Carboniferous
36 -- Moskovskiy
37 -- Podol'skiy
38 -- Kashirskiy
39 -- Vereyskiy
40 -- Bashkirskiy

Producing reservoir Cvr_3, which is confined to member X, is distinguished in the lower part of the Vereyskiy horizon. It corresponds to a clearly expressed maximum on the electric logging diagram. The reservoir thickness is sustained and equal to 5 to 6 m. The layers of traps (numbering 1 or 2 with a thickness of zero to 2 m) are confined mainly to the upper part of the reservoir. The producing reservoir in question in the roof is bounded by a layer of clayey limestone, frequently fissured and with stylolitic seams, with a thickness of 1.5 to 2 m. Therefore that layer is not always a reliable lithological cover, isolating producing reservoir Cvr_3 from the above-lying reservoir Cvr_2.

Producing reservoir Cvr_2 is characterized on the standard logging diagram by maximum KS values and negative PS anomalies. The mean reservoir thickness varies from 3 m in the west to 7 m in the east of the territory under consideration. It is well isolated from the above-lying producing reservoir Cvr_1 by rocks of terrigenous-carbonate composition with together with producing reservoir Cvr_2 form member IX.

In the composition of producing reservoir Cvr_2 up to five layers of traps are distinguished that are not sustained over either the section or the area.

Comparison of the sections of the producing reservoir based on detailed study of the field geophysical and geological materials has shown that the layers of traps distinguished in the section are well traced over the area.

In producing reservoir Cvr_2, as in producing reservoir C_2^1 (I), there is no dependence between the number of layers of traps and their total thickness (Figure 40).

To study the breakdown of reservoir Cvr_2 over three very extensive groups of deposits--the Igrovskaya, Dyurtylinskaya and Arlanskaya--the breakdown coefficients were calculated; they were 2.1, 2.7 and 2.5 respectively. These data show that in contrast with the reservoir C_2^1 (I) examined earlier the breakdown of reservoir Cvr_2 is far lower (Figure 41).

From the degree of development of traps in the section of producing reservoir Svr_2 on the area under consideration it is possible to distinguish two zones (Figure 43) with different values of the coefficient of granularity. The first zone embraces the territory from the Voyadinskoye deposit in the northwest to the Tatyshlinskoye in the northeast and the area of the Dyurtyulinskaya group of deposits. The coefficient of granularity of that zone, as a rule, is higher than 0.4.

The second zone passes parallel to the first and occupies a large part of the Arlanskaya, Nikolo-Berezovskaya, Novokhazinskaya, Manchirovskaya and other areas. Here the coefficient of "granularity" is mainly below 0.4. The coefficient of entropy of the rocks of producing reservoir Svr_2 of the Igrovskaya group of deposits varies from zero to 0.55. This indicates considerable homogeneity in the structure of reservoir Cvr_2 in comparison with reservoir C_2^1 (I) (Figure 44).

Producing reservoir Cvr_1, which is confined to member VIII, is bedded in the upper part of the Vereyskiy horizon and consists of limestones and dolomites. The total reservoir thickness in the western regions is not more than 1 to 3 m, and increases to 4.5 m toward the east (Yugomashevo and Tatyshly). The layers of traps with a total thickness of up to 1.5 m often have a lenticular structure. In eastern rayons the reservoir Cvr_1 is covered by dense clayey limestones, and in the region of the Arlanskoye deposit by limestones, argillites and marls.

Producing reservoir C_k of member VII is distinguished in the base of the Kashirskiy horizon. The reservoir is sustained in thickness (6.5 to 7.5 m) and is distinguished on logging diagrams by increased KS and negative PS anomalies. In that reservoir the layers of traps are very widespread. The fluctuation of the total thicknesses of the layers is not so considerable as in the producing part of the Upper Bashkirskiy substage. The maximum total thickness is 4 m, and the minimum is 1 m.

The breakdown coefficient for the Igrovskaya, Dyurtyulinskaya and Arlanskaya groups of deposits differs insignificantly and is 3.4, 3.2 and 3.6 respectively.

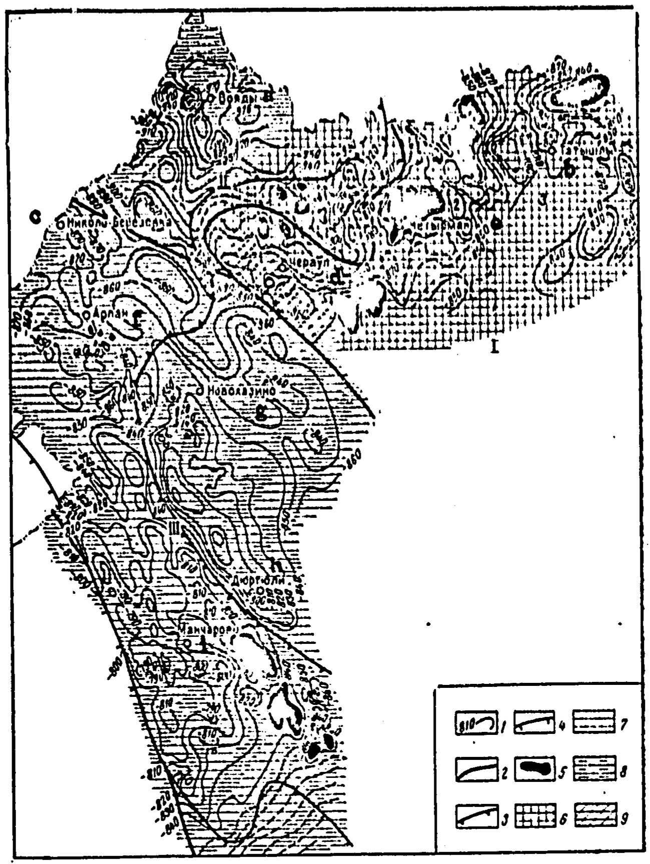


Figure 42. Diagram of the distribution of oil pools and the development of traps of the Upper Bashkirskiy substage of northwestern Bashkiriya. 1 -- roof isolines, in meters; 2 -- boundaries of structural and tectonic elements (according to data of the Laboratory of Regional Geology of the Bashkir State Scientific Research and Planning Institute of the Petroleum Industry); 3 -- boundary of the marginal part of the Late Devonian shelf (after M. A. Iunusov, 1970); 5 -- oil pools; zones of development of layers of collectors; 6 -- with a coefficient of granularity of over 0.2; 7 -- the same, from 0.1 to 0.2; 8 -- the same, less than 0.1; 9 -- zone of absence of collectors in upper part of section.

I -- Permsko-Bashkirskiy vault	1 -- Or'yebash-Cheraul'skiy nose
II -- Upper Kamskaya trough	2 -- Kuyedino-Gozhanskiy nose
III -- Birskaya saddle	3 -- Kudashevskaya trough

(Continued on next page)

a -- Voyady
b -- Tatyshly
c -- Nikolo-Berezovka
d -- Cheraul
e -- Chetyrman
f -- Arlan
g -- Novokhazino
h -- Dyurtyuli
i -- Mancharovo

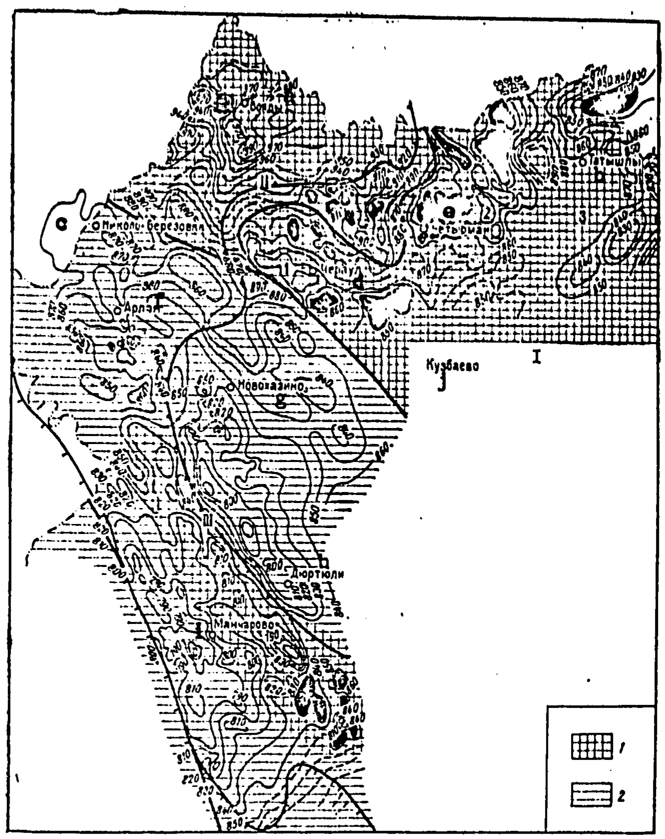


Figure 43. Diagram of the distribution of oil pools and the development of traps of producing reservoirs $Cvr_2 + Cvr_3$ of the Vereyskiy horizon of northwestern Bashkiriya. Zones of development of collectors: 1 -- with a coefficient of granularity of over 0.4; 2 -- the same, below 0.4. Other designations as for Figure 42. Add: j - Kuzbayevo.

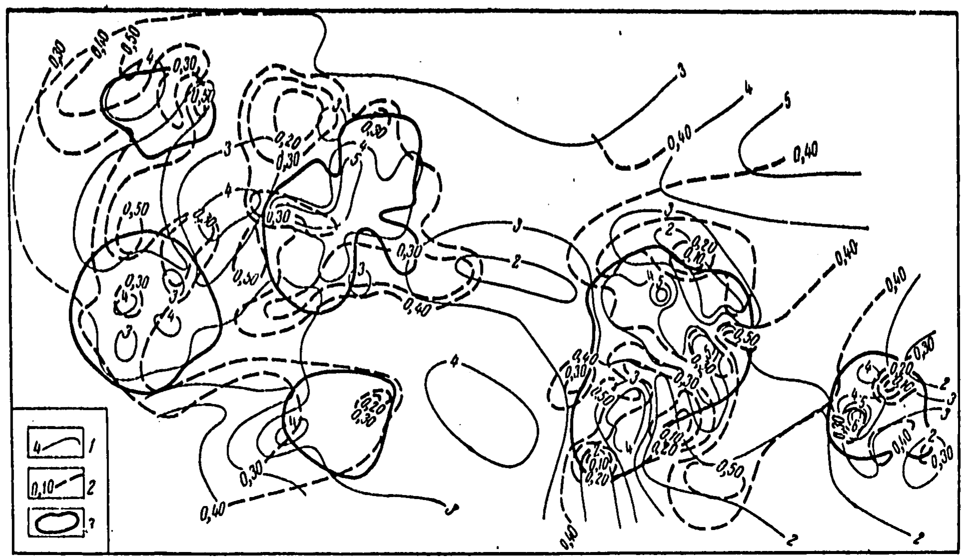


Figure 44. Distribution of coefficients of entropy and thicknesses of traps of reservoirs Cvr_2+ Cvr_3 of the Middle Carboniferous deposits of the Igrovskoye oil deposit.
Key: 1 -- iso-pachous lines of the total thickness of layers of collectors of producing reservoirs Cvr_2 + Cvr_3;
2 -- isolines of the coefficient of entropy;
3 -- upthrust contours.

From the degree of development of traps in the section of producing reservoir Ck, two zones can be distinguished on the territory under consideration (Figure 45). The first zone embraces a large portion of that territory and includes the areas of the Arlanskoye, Voyadinskoye, Yugomashevskoye and other deposits. On the whole characteristic of that zone is the presence of traps in the reservoir section and their increased (in comparison with the remaining part of the territory under consideration) total thickness and considerable extent. The value of the coefficient of granularity for the zone under consideration is higher than 0.4, as a rule. The second zone, which embraces the areas of the Mancharovskoye, Novokhazinskoye and other deposits, is poorer in traps and the coefficient of granularity of reservoir Ck in its limits is in the main less than 0.4.

A fairly thick reservor of clayey-carbonate rocks separates reservoirs Cvr_1 and Ck_1, but in places on stylolitic seams and fissures they are permeable.

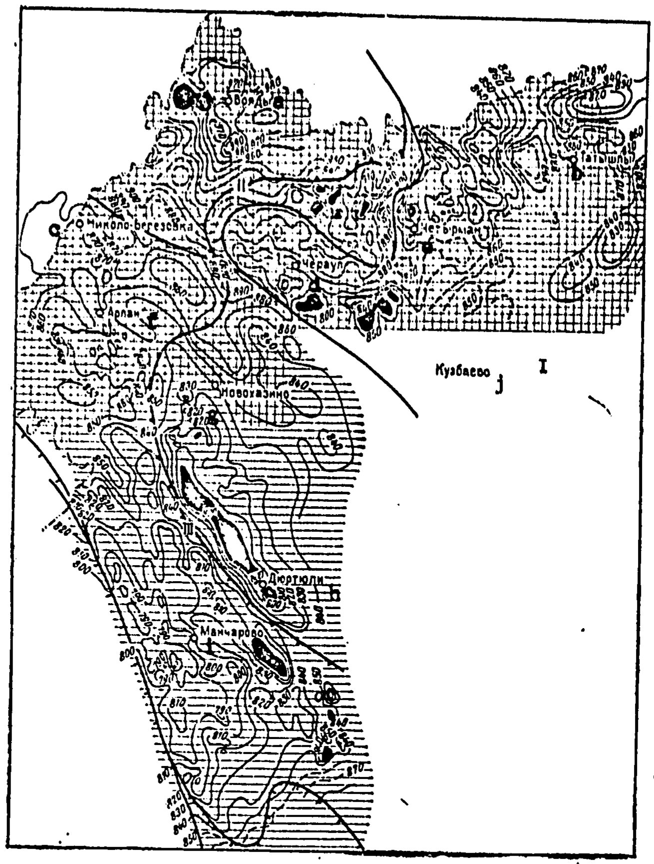


Figure 45. Diagram of the distribution of oil pools and the development of traps of producing reservoirs Ck_2, Ck_3 and Cvr_1 of the Kashiro-Vereyskoye deposits of northwestern Bashkiriya. Designations as for Figures 42 & 43.

Reservoir Ck is covered by a fairly thick formation of dense, frequently clayey limestones with layers of marls.

The above-lying producing reservoir Ck_1 has sharp lithological variability and persistence in the section on all the territory studied. Its thickness gradually increases in the eastern direction and in the region of the Chetyrmanskoye and Yugomashevskoye deposits reaches 10 m. The trap characteristics of the reservoir are sharply variable. The layers of traps are quite variable in thickness and are bedded in different parts of the of the section. They are poorly correlated even in adjacent wells and often have a lenticular structure.

The breakdown coefficient varies sharply both on deposits taken separately and on wells of a given deposit: its mean value is 2.8 for the Igrovskaya group of deposits, 1.3 for the Dyurtyulinskaya and 0.8 for the Arlanskaya.

Reservoir Ck_3 has high values of the coefficient of granularity, and only on isolated sections of areas of the Novokhazinskoye, Cheraul-Or'yebashskoye and Kuzbayevskoye deposit do they reach 0.2-0.3. On the remaining territory (of the Arlanskaya and Dyurtyulinskaya groups of deposits, the Voyadinskoye deposit, etc) the reservoir consists mainly of impermeable sulfatized carbonate rocks with single thin layers of traps (the coefficient of granularity does not exceed 0.1). The reservoir is covered by dense dolomitized clayey limestones with a thickness of 6-8 m.

Producing reservoir Ck_2 is traced on the entire territory under consideration and together with the dense rocks covering it forms member V. The layers of traps are very widespread on the Novokhazinskaya and Igrovskaya areas, that is, in the central parts of the studied territory. On those deposits a producing reservoir usually contains from three to five layers of traps. The maximum total thickness of the layers of traps does not exceed 5 m and their mean thickness is 3.8 m.

On other sections of the territory under consideration the layers of traps have not obtained wide distribution. On the area of the Dyurtyulinskaya and Mancharovskaya groups of deposits the layers of traps are replaced almost completely by impermeable rocks. Their coefficient of granularity is not greater than 0.1.

Producing reservoir Ck_1 is distinguished in the upper part of the Kashirskiy horizon. The structure of the reservoir has been well studied on the Arlanskoye deposit. An additional group of field geophysical (INNK) [Iraqi or Iranian National Oil Company] and field investigations permitted characterizing in greater detail the structure of the rocks of traps in that part of the section (Figure 46). A detailed layer correlation of the collectors was much facilitated by the presence in the section of reservoir Ck_1 of two layers of clayey dense limestone, with a mean thickness of 1.8 m, encountered in the sections of almost all wells and distinctly registered on the logging diagrams.

As a result of geological and geophysical investigations of the breakdown and comparison of the sections of all wells in producing reservoir Ck_1 on the Arlanskoye and Nikolo-Berezovskoye deposits, up to three interstratifications containing layers of traps have been distinguished.

The upper interstratification a, bedded in the roof part of the reservoir, with a thickness of up to 3 m, is well traced on the entire Arlanskaya area.

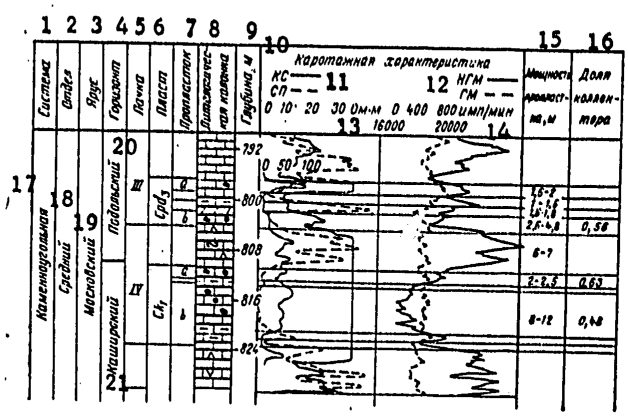


Figure 46. Typical geological-geophysical section of members III and IV of the Middle Carboniferous of the Arlanskoye deposit.

1 -- System
2 -- Series
3 -- Stage
4 -- Horizon
5 -- Member
6 -- Reservoir
7 -- Interstratification
8 -- Lithological column
9 -- Depth, m
10 -- Logging characteristics
11 -- KS and SP
12 -- NGM and GM
13 -- ohm•m
14 -- imp/min
15 -- Interstratification thickness, m
16 -- Share of traps
17 -- Carboniferous
18 -- Middle
19 -- Moskovskiy
20 -- Podol'skiy
21 -- Kashirskiy

It is a trap (63 percent of the thickness) and only in some wells is it replaced by dense rocks. The total thickness of the layers of traps fluctuates from zero to 2.4 m.

Interstratification a is separated from lower-lying interstratification b by a clayey-carbonate formation with a thickness of up to 2 m.

Interstratification b (with a thickness of 8 to 12 m) is the main commercial oil-bearing object of the Kashiro-Podol'skoye sediments of the Arlanskoye and Nikolo-Berezovskoye deposits. The layers of traps distinguished in its section are correlated well from well to well. Their number varies from 1 to 3. In some wells they merge into a single monolithic layer with a thickness that reaches 5 m. The total thickness of the trap fluctuates from 2 to 5.5 m and is 4.5 m on the average.

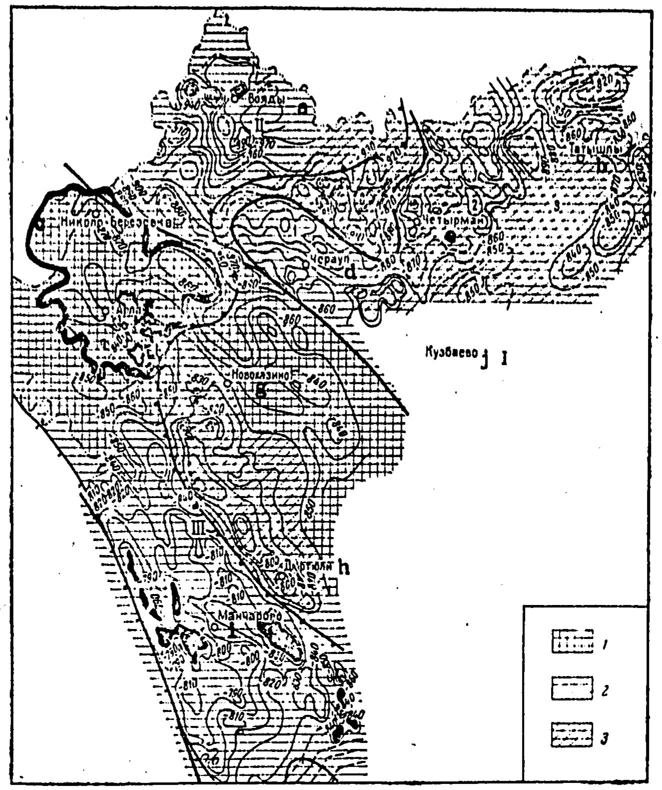


Figure 47. Diagram of the oil pool distribution and the development of traps of producing reservoirs Cpd_3 and Ck_1 of the Kashiro-Podol'skoye sediments of north-western Bashkiriya. Zones of development of layers of traps: 1 -- with a coefficient of granularity of more than 0.4; 2 -- the same, from 0.2 to 0.4; 3 -- the same, less than 0.2. Other designations as for Figures 42 & 43.

A layer of dense clayey-carbonate rocks is traced regionally in the base of interstratification b, separating it from the lower-lying sediments.

The described section of reservoir Ck_1 of the Arlanskoye deposits is very full. Its breakdown coefficient is 4.2. The total thickness of the rocks of the reservoir on the entire investigated territory varies from 7 m (in the east) to 16 m (in the west).

On the territory of northwestern Bashkiriya from the degree of development of the collectors of reservoir Ck_1 it is possible to distinguish three zones with different values of the coefficient of granularity. Zone I embraces the Arlanskaya and Nikolo-Berezovskaya areas of the Arlanskoye deposit and its coefficient of granularity is mainly greater than 0.4. Zone II (Dyurtyulinskoye, Mancharvoskoye, Or'yebash-Cheraulskoye and Voyadinskoye deposits) is characterized by reduction of the total thickness of traps and its coefficient of granularity varies from 0.2 to 0.4. Within zone III (Novokhazinskaya area and the Igrovskoye and Tatyshlinskoye deposits) the coefficient of granularity is reduced to zero (Figure 47).

The obtained values of the coefficients of entropy are used as some of the most important parameters of the characteristics of the structure of traps. Thus, at the Arlanskoye deposit the coefficient of entropy varies from zero to 0.50 and values of 0.2 to 0.35 predominate: this indicates the relatively sustained thickness of the layers of traps and their quantity in the section of producing reservoir Ck_1.

Producing reservoir Cpd_3 (included in the composition of member III) is distinguished in the base of the Podol'skoy horizon. The thickness of the reservoir is fairly persistent and is 5 to 7 m. Layers of traps are encountered in the lower part of the reservoir; in the upper they are absent or are observed very rarely and have a small thickness. Traps are encountered only in the northwestern part; in the remaining regions they amount to less than 5 percent of the total thickness of rocks of the reservoir. Reservoir Cpd_3 is covered by dense clayey limestones, the thickness of which is about 5 m on the Arlanskaya area.

Reservoir Cpd_2 is composed mainly of limestones. The content of porous layers in them amounts to about 25 percent of the thickness. The thickness of the reservoir reaches 15 m in the western regions and declines to 9 m in the eastern. The dense clayey limestone that covers the producing reservoir has a thickness of 10-12 m.

Reservoir Cpd_2 is fairly persistent in thickness (about 15 m) and is widespread. The content of porous varieties in its section amounts to about 20 percent. On logging diagrams it is characterized by irregular ρ_k and PS curves.

The investigations conducted on the character of the heterogeneity of the carbonate reservoirs of traps of northwestern Bashkiriya enabled the following conclusions to be drawn.

The layers of traps on producing reservoirs are irregularly distributed: they have received the greatest development in reservoirs Ck_1, Ck_4, Cvr_2 and C_2^1 (I), less in reservoirs Cpd_1 and Cpd_2, and the least in reservoirs ^{2} Ck_2, Ck_3, Cvr_1 and Cvr_3.

An increase in the total thickness of layers of traps of the Bashkir-Vereyskiy group of sediments is noted in the eastern regions of northwestern Bashkiriya. In the section of the Kashir-Podol'skiy group of sediments the increase of the total thickness of traps occurs in the western direction.

Study of the character of the heterogeneity of producing reservoirs on the basis of the coefficients of breakdown, granularity and entropy enabled the discovery of sections different in breakdown, and on the basis of the change of the total thickness of the layers of traps--zones of the propagation of permeable rocks of producing reservoirs revealed in the section of Middle Carboniferous sediments.

The discovery of such zones is of great importance in the selection of the direction of geological survey work, and also in solving questions connected with the planning and improvement of systems of development.

Chapter 4. The Structure of Oil Pools

One of the most important aspects of geological investigations in the planning of the development of an oil deposit is study of the structure of the oil pools. On the character of the structure of the pools will depend to a great extent the selection of the objects to be worked and the system of development, the geometry of the disposition of operating and pressure wells, the selection of methods of control and the regulation of oil production from reservoirs.

The structure of an oil pool is controlled by the surface of the roof and bottom of the producing reservoir, the water-oil contact surface, distinctive features of the distribution of reservoirs of collectors and variations of the physicochemical properties of the reservoir oil and water.

From synthesis of the results of study of the stratigraphy, lithology, tectonics, the structure of collectors and the hydrogeology of the area it is possible even in the initial stage to obtain a possibly complete idea of the principal parameters of a pool. To do that, all the primary geological-geophysical and field geophysical materials and data on the characteristics of the oil, gases and water must be processed. Only the complex study of all the materials makes it possible to establish in an early stage the main features of the structure of pools and take them into account in planning.

On the example of the Arlanskoye deposit we will examine experience in studying distinctive features in the structure of oil pools and the use of the obtained data in selecting a production system.

The Structure of the Oil Pools of the Arlanskoye Deposit

The Arlanskoye deposit is situated in the Birskaya saddle, which is complicated by second-order structures--arches with a northwestern course.

The area of the Arlanskoye oil deposit, in contrast with most deposits of Volgo-Ural'skaya Oblast, which are confined to a terrigenous formation of the Lower Carboniferous, is characterized by considerable dimensions and reserves. Even such relatively large deposits as the Mukhanovskoye, Pokrovskoye (Kyubyshevskaya Oblast), Lobanovskoye and Kuyedinskoye (Permskaya Oblast) and Voyadinskoye and Mancharovskoye (Bashkir ASSR) can be compared only with individual sections of it.

The Arlanskaya structure along the roof of the terrigenous formation of the Lower Carboniferous has an asymmetric structure with steeper western and gently sloping eastern limbs (Figure 48). The long axis of the structure is in northern and northwestern directions. The structure is complicated by

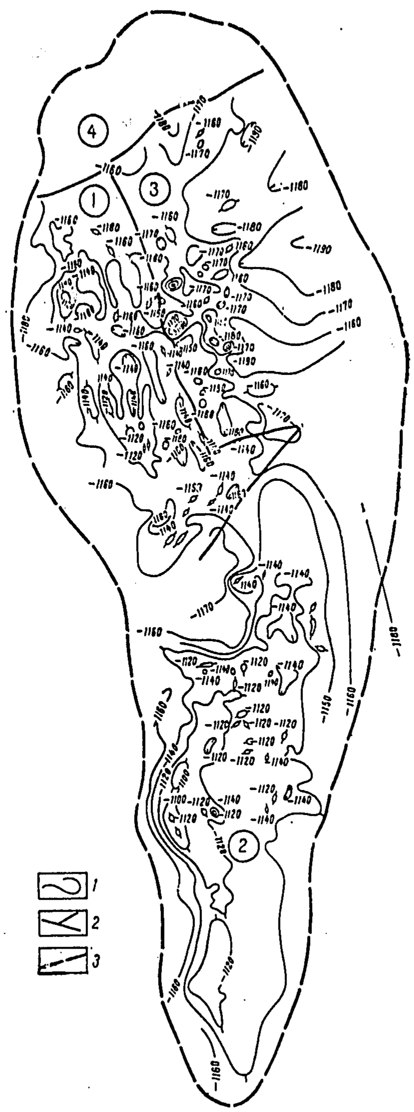


Figure 48. Diagram of the structural plan of the terrigenous formation of the Lower Carboniferous of the Arlanskoye oil deposit.

1 -- contour lines, m
2 -- boundaries of areas
3 -- provisional boundary of Arlanskoye oil deposit

Areas: 1 -- Arlanskaya
2 -- Novokhazinskaya
3 -- Nikolo-Berezovskaya
4 -- Vyatskaya

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upthrusts of a smaller order of magnitude: domes, structural noses and troughs. Domes are confined mainly to the western part of the structure and form "chains" with a northern and northwestern direction. Saddles of different amplitudes are traced between them. Very deeply submerged and small in dimensions saddles are noted in the central part of the structure and in the northwest. A dome has various dimensions (from 0.3 x 0.2 km to 5.5 x 4 km) and amplitudes (10 to 60 m) and is traced on the surfaces of all producing reservoirs (Figure 49). The contour line -1170 m is on the western limb and -1155 m on the eastern.

Distinctive features of the structure of the surface of the terrigenous formation of the Lower Carboniferous of the Arlanskaya area are characteristic of deposits of Bashkiriya and other regions.

The relief of the surface of the Turneyskiy limestones is more sharply broken up because of the presence of local sections on which the Turneyskiy carbonate sediments are washed out to different depths.

Oil pools in the Lower Carboniferous terrigenous formation relate mainly to Bobrikovsko-Radayevskiy (reservoir C-VI) and Tul'skiy sediments (Figures 1, 2 & 50).

The position of the water-oil contact in the pools of reservoir C-VI is controlled by a structural factor. According to field geophysical data the oil-water interface is established rather distinctly (Figure 51) in 70 percent of the wells of the water-oil zone, and in 30 percent of the wells on the oil-water contact clayey layers with a thickness of 0.8 to 7.7 m are noted.

On the Arlanskaya area over three tens of oil pools are confined to the reservoir C-VI. The water-oil contact surfaces on individual pools are submerged in northwestern direction with absolute marks of -1175, -1176 m and up to -1188 m (Table 8).

Large pools with an area of 30 to 50 ha are on marginal sections of the Arlanskaya oil-bearing area, with different water-oil contacts (from -1176 to -1185 m).

Characteristic of pools of reservoir C-VI of the Arlanskaya area is linear extension at a small width, the presence of bottom waters on the main part of the oil-bearing area and a head of the contour waters.

Oil pools confined to reservoir C-VI have extensive water-oil zones (in view of the gently sloping angles of inclination of the layers).

Such parameters as a coefficient representing the ratio of the oil-saturated thickness of the reservoir to the water-saturated (h_o/h_w), the coefficients of breakdown and of coherence of reservoirs in the water-oil zone and in the region beyond the outline, and the mean oil-saturated and water-saturated thicknesses of the reservoir (Table 9) were used to characterize the water-oil pools.

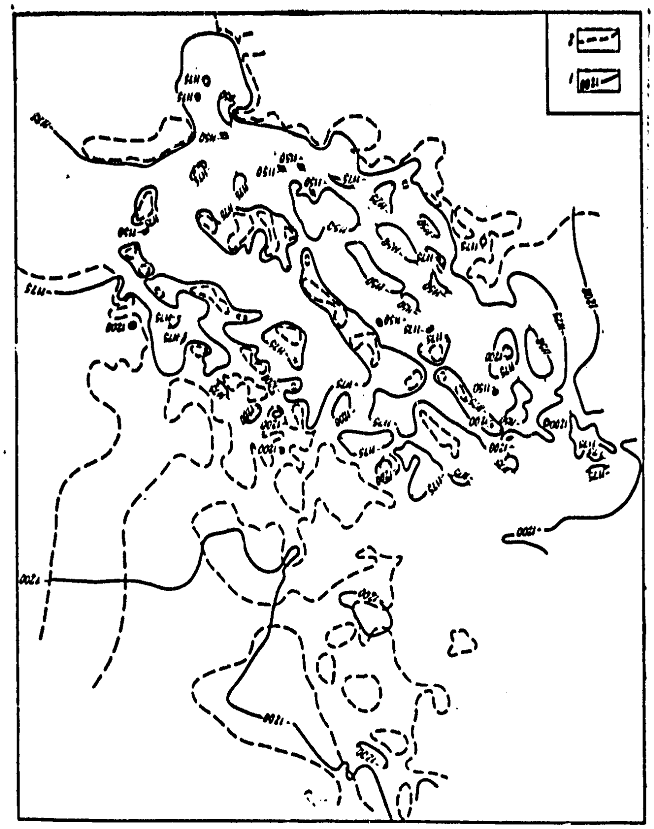

Figure 49. Diagram of the structural plan of the roof of reservoir C-V of the Arlanskaya area. 1 -- contour lines through 24 m; 2 -- oil pool outline of reservoir C-V.

For water-oil pools confined to reservoir C-VI in the region of the Arlanskaya area the following is characteristic.

In all pools h_o/h_w is mainly less than 1 and fluctuates from 0.34 to 0.8, k_{br} from 1.2 to 2.04 and k_{coh} from 0.21 to 0.73. The water-oil contact surface usually is not confined to the level of clayey sections; h_{av-w} beyond the oil pool outline, as a rule, is higher than h_{av-w} of the water-oil part. The pools are characterized by a hydraulic system. Wells are rapidly flooded due to the advance of bottom and contour waters along "corridors" of highly permeated collectors.

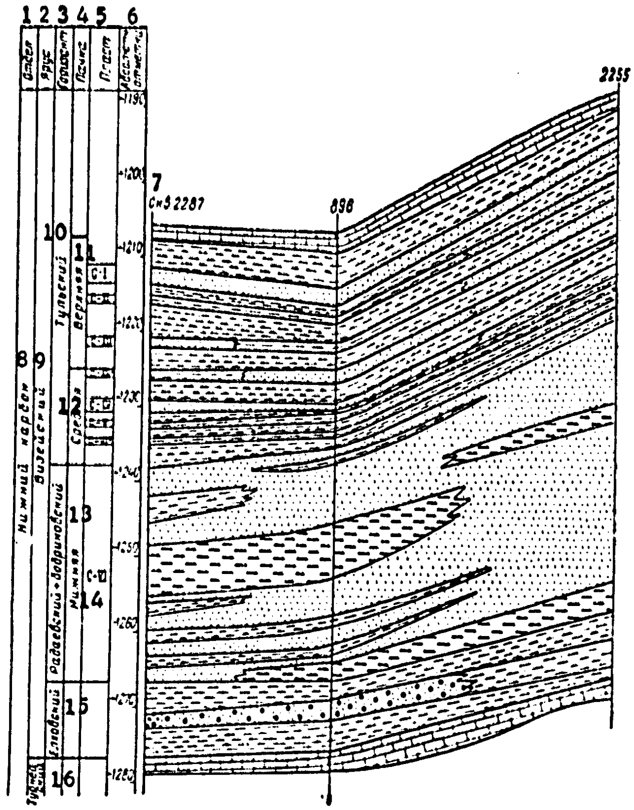

Figure 50. Geological profile along the line wells 2287-2255 of the Sauzbashevskaya area.

1 -- Series
2 -- Stage
3 -- Horizon
4 -- Member
5 -- Reservoir
6 -- Absolute marks
7 -- Well
8 -- Lower Carboniferous
9 -- Vizeyskiy
10 -- Tul'skiy
11 -- Upper
12 -- Middle
13 -- Radayevskiy + Bobrikovskiy
14 -- Lower
15 -- Yelkhovskiy
16 -- Turneyskiy

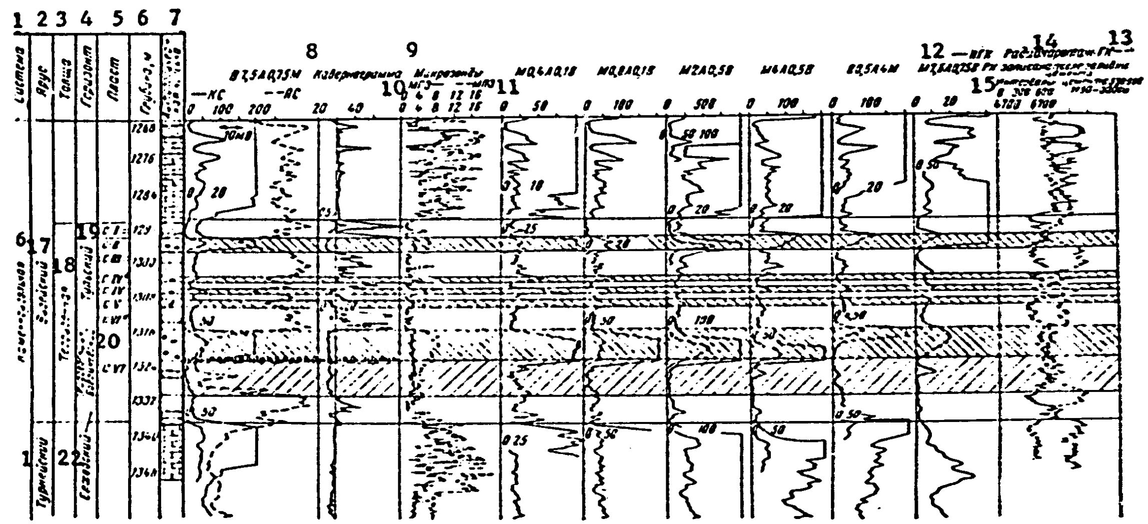

Figure 51. Geophysical complex of well investigations.

1 -- System
2 -- Stage
3 -- Formation
4 -- Horizon
5 -- Reservoir
6 -- Depth, m
7 -- Lithological column
8 -- Cavernogram
9 -- Microsondes
10 -- MGZ
11 -- MPZ
12 -- IGK
13 -- GK
14 -- Radiologging recorded after pouring of cement
15 -- Intervals of cement
16 -- Carboniferous
17 -- Vizeyskiy
18 -- Terrigenous
19 -- Tul'skiy
20 -- Radayevskiy + Bobrikovskiy
21 -- Turneyskiy
22 -- Yelkhovskiy

Table 8 Characteristics of oil pools of reservoir C-VI of the Arlanskoye deposit

Местоположение 1	Характеристика залежи 2	Размер залежи, км 3	Абсолютная отметка ВНК, м 4
	5 Новохазинская площадь		
6 Основная залежь	7 Нефтяная	12×(2,5—3,8)	8 —1167,1÷—1169,4
9 Северная залежь (Шарипово)	10 Водонефтяная	16×(2—6)	—1173÷—1175
	11 Арланская площадь		
12 Юго-восточная (Уртаул)	10 Водонефтяная	3,5×(1,0—1,5)	—1175÷—1176
13 То же	»	5×(0,5—1,0)	—1175÷—1176
14 Юго-западная (Ашит-Нагай)	7 Нефтяная	20×(2,5—6)	—1177÷—1180
15 Центральная (Арлан)	10 Водонефтяная	13,5×(0,7—3,5)	—1177÷—1178
16 Северная (на северо-восток от Ашита)	»	6,5×(0,7—1,2)	—1184÷—1185
17 Северо-восточная	»	4,5×1,0	—1183÷—1185
18 Северо-западная	»	4,0×(1—2,5)	—1188
	19 Николо-Березовская площадь		
20 Северо-западная	10 Водонефтяная	4×0,6	—1192,4
21 Юго-западная	»	4×(0,5—2)	—1192,4

Key:
1 -- Deposit
2 -- Type of pool
3 -- Pool dimensions, km
4 -- Absolute water-oil mark, m
5 -- Novokhazinskaya area
6 -- Main pool
7 -- Oil
8 -- ÷ = to
9 -- Northern pool (Sharipovo)
10 -- Water-oil
11 -- Arlanskaya area
12 -- Southeastern (Urtaul)
13 -- Ditto
14 -- Southwestern (Ashit-Nagay
15 -- Central (Arlan
16 -- Northern (northeast of Ashit)
17 -- Northeastern
18 -- Northwestern
19 -- Nikolo-Berezovskaya area
20 -- Northwestern
21 -- Southwestern

According to the position of the water-oil contact in reservoir C-VI, the Novokhazinskaya area is divided into two sections.

In the main section the water-oil contact surface is traced at the absolute marks of -1167.1 and -1169.4 m (69 wells). On the eastern gently sloping limb the outer oil pool outline is a tortuous line: on three sections it enters deeply (from 2 to 5 km) into the internal part of thepool. In the inner oil pool outline several submerged sections were registered in which the sandstones of reservoir C-VI also are saturated with water. The water-oil contact surface on those sections fluctuates from -1167 to -1172.9.

In the southern part of the pool the water-oil contact rises to the -1163-m makr. The main pool is separated from the northern by a trough of latitudinal direction entering from the east and a lithological shield from the west.

On the northern section the water-oil part is confined to the eastern limb of the structure. The water-oil contact surface is traced at the absolute marks of -1174 to -1175 m. In the central part of the water-oil pool, closed submerged sections with an area of up to 300 ha are observed, where reservoir C-VI is saturated with water as on the main part of the Novokhazinskaya area. Small completely oil-saturated sections are noted.

Thus the structure of the oil pools of reservoir C-VI of the Novokhazinskaya and Arlanskaya areas differs considerably; pools of the former area are very large in dimensions. Narrow linearly extended pools, supported on all sides by contour waters, are noted only in the extreme north, on the boundary with the Arlanskaya area.

Water-oil parts in the region of the main pool of reservoir C-VI of the Novokhazinskaya area are noted in the eastern and western limbs of the structure. Characteristic of three sections of the water-oil zone of the Novokhazinskaya area is a value of the coefficient h_o/h_w greater than 1 (133-1.51); k_{br} fluctuates from 1 to 1.5 and k_{coh} from 0.6 to 0.9. The mean thickness beyond the oil pool outline, as a rule, is higher than the water-saturated thickness in the pool outline. On water-oil sections of pools of reservoir C-VI on the Novokhazinskaya area the conditions are more favorable for development.

There are two small pools in the western part of the Nikolo-Berezovskaya area with water-oil contact at the marks -1192.5 and -1197.5 m. On the Nikolo-Berezovskaya area five small water-oil pools have been found.

The position of the water-oil contact on the Arlanskoye deposit is controlled mainly by the structural factor. On isolated pools of reservoir C-VI submergence ot the water-oil contact is observed in northwestern direction from -1156 m (the extreme south of the Novokhazinskaya area) to -1193 m (the Nikolo-Berezovskaya area).

A definite regularity is noted in the degree of filling of the traps with oil. Traps confined to reservoir C-VI are completely filled with oil only in the southeastern, most elevated part of the structure. In the northwestern direction the degree of their filling gradually decreases. The amplitudes of the structures fluctuate more (from 10-15 to 40-60 m) than the absolute marks of the water-oil contact surface.

The oil pools are of the structural, rarely the structural-lithological type. The regime of the pools is mainly hydraulic and elasto-hydraulic.

The absolute marks of the water-oil contact surface in reservoirs C-VI^0, C-V, C-IV and C-IV^0 in the main correspond to the marks of the water-oil contact surface traced in pools of reservoir C-VI. On the Novokhazinskaya area the collectors of those reservoirs are completely oil-saturated.

The persistence of clayey layers--reference marks in the middle part of the terrigenous formation, indicates absence of a hydrodynamic connection between individual producing reservoirs in the vertical section, and the discontinuous character of the development of collectors--a very weak connection of them over the area. The oil pools are mainly of the lithological and structural-lithological types.

On the Novokhazinskaya area the water-oil contact in reservoir C-II is traced in 30 wells. According to the absolute position of the water-oil contact surface in pools of reservoir C-II the entire oil-bearing zone is divided into two sections corresponding mainly to sections of pools of reservoir C-VI, but the boundary of change of the water-oil contact is shifted a little to the north. The lithological shield is shifted in the same direction. The deep setting of the latitudinal trough also found clear reflection on the roof of reservoir C-II (as on C-VI), but it had no effect on the position of the water-oil contact surface on sections adjacent to it on the north and south (-1144.6 m and -1145.6 m). However, change of the water-oil contact surface by 14 m is connected with a large lithological shield north of the trough and intersecting the structure transverse to its course. In the northernmost part of the Novokhazinskaya area the water-oil contact surface becomes a single one for reservoirs C-II and C-VI (-1174 m).

The different position of the water-oil contact surface in pools of the Novokhazinskaya area creates a very different arrangement in the plane of water- and oil-saturated reservoirs on marginal sections (Figure 52): above an oil pool of reservoir C-VI and its water-oil part a water-oil or water-saturated reservoir C-II is developed; reservoirs C-II and C-VI are water-saturated, and in reservoirs C-IV and C-V an oil or a water-oil pool is noted; at the same time, water-oil pools are confined to reservoirs C-II and C-VI, and oil, etc, to reservoirs C-IV, C-V and C-VI^0.

On the Arlanskaya area in reservoir C-II the water-oil contact is traced on some marks with reservoir C-VI, and only in the southwest of the area is it 3 to 4 m lower than in reservoir C-VI.

On the Nikolo-Berezovskaya area reservoir C-II on a considerable part of the oil pool outline also has a lithological shield. The pools are of the structural lithological type. Reservoir C-I has a lenticular development and is completely oil-bearing. The oil pools of reservoirs C-I and C-III are of the lithological and more rarely the structural-lithological types and their regime can be defined as a regime of dissolved gas.

At the Arlanskoye deposit the industrial oil bearing of sandstones of the Aleksinskiy horizon has been established: three small pools are distinguished,

Table 9 Coefficients and separate parameters characterizing water-oil pools of reservoir C-VI and separate sections of them on areas of the Arlanskoye deposit

1 Площадь, участок, залежь	Мощность, м 2			3 Отношение нефтенасыщенной мощности к водонасыщенной	4 Расчлененность $k_{расчл}$	5 Песчанистость $k_{песч}$
	6 нефтенасыщенная	7 водонасыщенная в контуре нефтеносности	8 водонасыщенная за контуром нефтеносности			
9 **Арланская площадь**						
10 Сакловская	6,2	9,9	9,0	0,63	1,8	0,52
11 Ашитская	5,3	6,7	5,7	0,8	2,04	0,21
12 Залежь к северо-востоку от Ашита	6,2	5,2	8,3	1,1	2,0	0,28
13 Залежь на границе с Николо-Березовской площадью	2,7	7,1	8,6	0,38	2,1	0,24
14 Южная часть Новонагаевского участка	7,6	9,1	10,8	0,83	1,31	0,73
15 Крупная залежь на севере от Новонагаево	3,6	10,6	9,8	0,34	1,52	0,61
16 **Новохазинская площадь**						
17 Восточное крыло, основная залежь	6,5	4,3	6,1	1,51	1,5	0,6
18 Западное крыло, основная залежь	5,6	4,2	6,3	1,34	1,0	0,9
19 Северная залежь, восточное крыло	6,0	4,5	6,7	1,33	1,27	0,73

Key:
1 -- Area, section, pool
2 -- Thickness, m
3 -- Ratio of oil-saturated to water-saturated thickness
4 -- Breakdown k_{br}
5 -- Arenosity k_{ar}
6 -- oil-saturated
7 -- water-saturated in oil pool outline
8 -- water-saturated beyond oil pool outline
9 -- Arlanskaya area
10 -- Saklovskaya
11 -- Ashitskaya
12 -- Pool northeast of Ashit
13 -- Pool on boundary with Nikolo-Berezovskaya area
14 -- Southern part of Novonagayevskiy section
15 -- Large pool north of Novonagayevo
16 -- Novokhazinskaya area
17 -- Eastern limb, main pool
18 -- Westerl limb, main pool
19 -- Northern pool, eastern limb

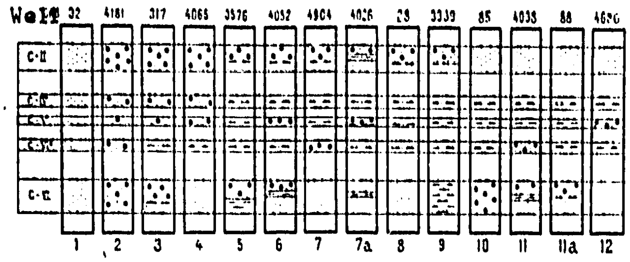

Figure 52. Position of initial water-oil contacts in producing reservoirs of the Novokhazinskaya area.

that are confined to different lenses (Figures 35, 36). The oil-saturated thickness of the collectors fluctuates from 1 to 9.8 m. The water-oil contact surface is inclined toward the north and the water-oil contact marks are lowered from -1131,8 to -1153 m. The width of the sandstone zone varies from 400 m to 1.5 km. The pools are of the lithologically bounded type.

The oil-bearing areas of the oil pools of the Arlanskoye deposit, confined to different reservoirs, do not coincide in the plane and amount to from 5 to 80 percent of the total area included in the composite outline. This peculiarity of the structure of the pools plays a large role in the development of the oil deposit.

The initial rock pressure, reduced to the water-oil contact mark (-1180 m on the Arlanskaya area and -1165 m on the Novokhazinskaya) is 141 kgf/cm^2. The initial pressures in reservoirs C-VI, C-II and C-V are practically identical and are 140.5 kgf/cm^2.

The water pressure of the terrigenous formation is considerably below the pressures of the Sakmaro-Artinskiy and Kashiro-Podol'skiy waters.. Thus the piezometer mark, reduced to the plane of comparison is 2000 m, for the terrigenous formation is 125 m and 142 m below the marks of the piezometers for the Kashiro-Podol'skiy and Sakmaro-Artinskiy horizons respectively. When there is a connection overflow of the terrigenous formation into the reservoirs is possible.

The character of the change of the rock pressure during operations indicates the presence of an active head of edge waters in sandstones of reservoir C-VI and very weakly in the upper lenticular sandy-siltstone reservoirs.

The initial regime of the oil pools in reservoir C-VI is defined as elasto-hydraulic. For reservoirs of the Tul'skiy horizon (C-I, C-II, C-III, C-IV^0, C-IV, C-V and C-VI[0]) a regime of dissolved gas is observed in the main. The process of maintenance of rock pressure in pools confined to individual reservoirs and multireservoir deposits during their combined development is a very complicated task.

Thus the main features characterizing the structure of oil pools confined to reservoir C-VI of the Arlanskaya area are: the relatively small oil-bearing area (about 35 percent), the presence of a large number of pools, their small dimensions and linearly extended form, the large summary perimeter of the outer oil pool outline, the good trap properties and breakdown of the section and the activity of the region beyond the outline. Characteristic of pools of reservoirs C-IV and C-V are their isolation and inactivity of the stratal waters, connected with the lenticular structure and small thickness of the traps.

In the first stage of planning, in the compilation of a technological plan for the development of the Arlanskaya area and the general plan of the Arlanskoye deposit, taking into account distinctive features of the structure of the pools, the following basic elements of the development system were selected:

1) a single object of exploitation on the Arlanskaya area, one including the entire producing formation, and two objects of exploitation on the Novo-khazinskaya area;

2) extra-outline flooding for oil pools of reservoir C-VI and intra-outline flooding for all the remaining part of the producing formation, and linear arrangement of series of operating and pressure wells during intra-outline flooding.

With the activity of the extra-outline region of reservoir C-VI and the inactive regime in the upper reservoirs taken into account, various pressures were envisaged for pressurizing the water--100 kgf/cm^2 for reservoir C-VI and 150 kgf/cm^2 for relatively impermeable reservoirs.

The experience of the first years of development of the Arlanskoye deposit and the new oil field geological information obtained in drilling hundreds of operating wells have shown that not all the initially assumed basic positions of the development systems are optimal and that they require further improvement. Later the system of disposition of pressure and operating wells was partially changed and supplemented, changes were introduced in the practice of distinguishing objects of exploitation, and the pumping of water into the extra-outline region was reduced or completely halted. The conditions which caused those changes are discussed below.

Oil Pools in Carbonate Deposits

Carbonate deposits contain formations of various types. In their basic structure and morphological characteristics they are similar to the terrigenous. Formations of the sheet-vault type are very widespread in Uralo-Povolzh'ye. Oil traps are local elevations of various amplitude. Most of those elevations are connected with thick reservoirs of carbonate deposits containing layers of traps, sustained over a large area.

Besides sheet-vault and carbonate traps, massive deposits are widespread. Traps of that type can be the vaults of structures with thick reservoirs of carbonate deposits and also masses of reef origin. Deposits of the massive-sheet type are encountered more rarely.

Lithological-structural deposits are distributed insignificantly on the territory under investigation. Such deposits are encountered within the limits of structures when on individual sections there is lithological replacement of producing reservoirs containing oil by dense rocks.

Producing horizons consist of a frequent alternation of dense and porous varieties of carbonate rocks. In a number of deposits there is an absence of a hydrodynamic connection between individual reservoirs, as a result of which there are considerable fluctuations of the levels of water-oil contacts. The oil pool outlines of individual reservoirs of a producing band of carbonate deposits acquire a complex configuration and at times water-bearing or gas-bearing layers are found between them.

The enumerated distinctive features of the structures of carbonate rocks present special requirements for the system of development of gas pools, since the processes of filtration of liquids is made difficult to a considerable degree by the complexity of the micro- and macrostructure of the carbonate traps.

As an example we will present the structure of producing deposits in the Middle Carboniferous deposits of northwestern Bashkiriya, a structure characteristic of many deposits.

The established rhythmic alternation of producing reservoirs, the revealed distinctive features of the structure of the covering rocks (above all the presence of fissures in the covering rocks), and also data on the position of the water-oil contact permit distinguishing in the section of Middle Carboniferous deposits of northwestern Bashkiriya six independent oil-bearing objects (Figure 53).

The first oil-bearing object is confined to the producing reservoirs $Cpd_3 + Ck_1$ of the Kashiro-Podol'skiy deposits, the second to the producing reservoir Ck_2 of the Kashirskiy horizon, the third to producing reservoir Ck_3 of the Kashirskiy horizon, the fourth to producing reservoirs Ck_4 and Cvr_1 of the

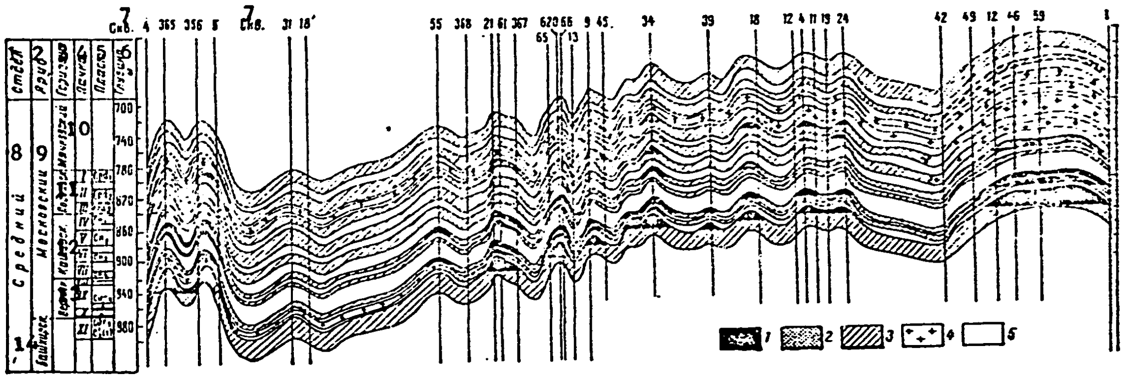

Figure 53. Schematic geological profile of deposits of the Middle Carboniferous along the line Voyady-Taushi. 1 -- reservoirs with local oil content; 2 -- the same, with presumed oil content; 3 -- the same, water-bearing; 4 -- the same, with inconsiderable thickness of traps; 5 -- dense reservoirs.

1 -- Series
2 -- Stage
3 -- Horizon
4 -- Member
5 -- Reservoir
6 -- Thickness, m
7 -- Well
8 -- Middle
9 -- Moskovskiy
10 -- Myachkovskiy
11 -- Podol'skiy
12 -- Kashirskiy
13 -- Vereyskiy
14 -- Bashkirskiy

Kashir-Vereyskiy deposits, the fifth to producing reservoirs Cvr_2 and Cvr_3 of the Vereyskiy horizon and the sixth to producing reservoir C_2^1 (I) of the Upper Bashkirskiy substage.

The different degree of heterogeneity of producing reservoirs, change of their trap properties and thicknesses, and also distinctive features of the structure of oil pools determina a complex character of the oil distribution in the section of the Middle Carboniferous deposits.

Reservoirs Ck_1, Cvr_2 and C_2^1 (I), which are the main commercial oil-bearing objects of the Middle Carboniferous, have good trap properties and considerable thicknesses of the layers of traps, and also a more homogeneous structure. Producing reservoirs Cpd_3, Ck_4 and Cvr_3 have somewhat worse trap properties and greater heterogeneity in the structure of layers of traps, because of which their commercial value diminishes.

Producing reservoirs Ck_2 and Ck_3 have sharp lithological variability. Characteristic of them is worsening of the trap properties and reduction of the thicknesses of the layers of traps. They are not very productive from the point of view of oil yield.

The commercial oil content of the Upper Bashkirskiy substage is connected with producing reservoir C_2^1 (I) (VI is an oil-bearing object), which is traced in the upper part of the Upper Bashkirskiy substage (Figure 40).

Oil and gas pools confined to producing reservoir C_2^1 (I) have been established on the Tatyshlinskoye, Yugomashevskoye, Maksimovskoye, Igrovskoye, Itkinevskoye, Kuzbayevskoye, Taymurzinskoye, Chetyrmanskoye and Karacha-Yelinskoye deposits (Figure 42).

Oil pools of producing reservoir C_2^1 (I) are of the massive-sheet type and are confined to third-order structures. The structure of the producing reservoir is considerably heterogeneous: the layers of traps encountered in its section are bedded in the form of lenses of different length and thickness and are interconnected by fissures. The initial oil discharge of the wells reach 70 tons per day.

Within the limits of the northeastern group of deposits (the Tatyshlinskoye, Yugomashevskoye, Maksimovskoye, Teplyakovskoye, Igrovskoye, Kuzbayevskoye, Chetyrmanskoye, etc) oil pools of producing reservoir C_2^1 (I) are confined to the vault parts of elevations. In all, 17 individual oil pools have been discovered there, differing in the dimensions and stages of oil content and different total thicknesses of oil-bearing traps. Thus, in a number of oil pools of the Yugomashevskoye and other deposits the thickness of the oil-bearing traps is not more than 2 m. In some pools of the Kuzbayevskoye and Teplyakovskoye deposits it is 4 to 6 m, and within the Igrovskaya group of elevations it reaches 10 to 12 m. Oil-saturated traps of producing reservoif C_2^1 (I) usually consist of 4 to 8 layers, but sometimes their number increases to 11. Monolithic oil-bearing layers are encountered nowhere.

In the limits of the southeastern group of deposits the oil traps of producing reservoir C_2^1 (I) form four isolated pools of different sizes, confined to the vault parts of elevations (Figure 42). The largest of them is confined to the Taymurzinskoye elevation, where the thickness of oil-saturated traps reaches 4 m. The remaining pools have small dimensions, and the thickness of the oil-saturated traps does not exceed 2 m. The number of oil-bearing layers changes from 1 to 5.

Within the limits of the Igrovsko-Chetyrmanskaya group of deposits a regular lowering of the water-oil contact marks of pools westerly has been established. This lowering occurs in stages from pool to pool and on the whole over the area is in the range of marks from -837 to -908 m. The stepwise lowering of the water-oil contact toward the west is caused by the tectonic factor and occurs simultaneously with a general submergence of the Middle Carboniferous sediments in the same direction. Within the limits of small pools the water-oil contact surface, as a rule, is horizontal. On steeper pools a slight lowering of that surface (of up to 5 m) in western direction is observed, in the direction of the regional submergence of the Middle Carboniferous sediments.

A similar mechanism of stepwise submergence of the water-oil contact has also been established on the area of the Dyurtyulinskaya group of pools, with the difference that the lowering of the water-oil contact marks from -815 to -840 m occurs in a southeast direction that coincides with the regional inclination of the Middle Carboniferous deposits in that region.

The commercial oil content of the Vereyskiy horizon is connected with producing reservoirs Cvr_1, Cvr_2 and Cvr_3. Producing reservoir Cvr_1 is traced in the upper part of the horizon and forms with reservoir Ck_4 a single oil-bearing object, and therefore the oil-bearing prospects of those reservoirs have been examined jointly with the Kashirskiy horizon. Producing reservoirs Cvr_2 and Cvr_3 are bedded in the lower part of the Vereyskiy horizon (oil-bearing object V).

There are 19 oil pools in reservoirs Cvr_2 and Cvr_3. In the plan they are well inscribed in the outlines of pools of lower-lying producing reservoir C_2^1 (I). In addition, oil pools are encountered on the Or'yebash-Cheraul'skaya area.

The oil pools of reservoir Cvr_2 are of the sheet-vault type. The traps have a fairly sustained character of development over the area. They are isolated from above and below by impermeable varieties of rocks. The total oil-saturated thickness of the traps depends on their total thickness and the structural tectonic factor (the maximum thicknesses of oil-saturated traps are confined to vaults of the elevations). Within the found oil traps those thicknesses fluctuate from 0.5 to 5 m and more rarely increase to 7 m (the Igrovskoye deposit, Figure 44). The oil pools of reservoir Cvr_3 are of the lithological stratigraphic type.

The discovered oil pools of reservoirs Cvr_2 and Cvr_3 (object V) are not identical in productivity. Pools of the Igrovskoye deposit have the best trap properties and larger productivity. The production of wells during testing reaches 20 tons per day.

Oil pools of the Dyurtyulinskaya group of deposits are characterized by low trap qualities and very low productivity. The mean well production here is 4 to 10 tons per day. Producing reservoirs Ck_4 and Cvr_1 of the Kashiro-Vereyskiy deposits, separated by a clayey-carbonate reservoir, constitute oil-bearing object IV.

The commercial oil pools confined to the layers of traps of producing reservoirs Ck_4 and Cvr_1 are of the sheet-vault type and are known at the Voyadinskoye, Igrovskoye, Chetyrmanskoye and Kuzbayevskoye deposits. The daily oil production of the wells are small, as a rule, and only in individual wells with a mean trap thickness of 4 m does it reach 10 tons.

In producing reservoir Ck_3 (oil-bearing object III) layers of traps are encountered mainly in the northern regions. They are bedded for the most part in the form of thin lenses in various parts of the reservoir section. Their commercial oil content has been established by single wells on the Novokhazinskaya area. Their productions are small (1.5-2 tons per day).

In traps of producing reservoir Ck_2 (oil-bearing object II) small oil pools with independent water-oil contacts have been discovered in the Cheraul'skaya and Kuzbayevskaya deposits (Figure 45). Within the discovered pools the oil-bearing traps have a total thickness of from zero to 6 m and usually consist of four to six layers.

In the carbonate traps of producing reservoirs Cpd_3 and Ck_1 (oil-bearing object I) of the Kashiro-Podol'skiy deposits commercial oil content was discovered on the Arlanskaya and Nikolo-Berezovskaya areas. On the Mancharovskaya and Dyurtyulinskaya groups of deposits adjacent to them commercial oil content has been established only in producing reservoir Ck_1, and the rocks forming reservoir Cpd_3 are of a dense variety.

Thirteen oil pools of the sheet-vault type have been found. The largest oil pool embraces territory of the Arlanskaya and Nikolo-Berezovskaya areas. The total oil-saturated thicknesses of the traps there vary from zero to 10 m. The water-oil contact surface gradually sinks in a northwestern direction from mark -722.5 m in the central part of the Nagayevskiy elevation to -744 m on the Nikolo-Berezovskaya area. The pool is surrounded on all sides by contour waters.

On areas of the Mancharovskaya and Dyurtyulinskaya groups of deposits the traps of producing reservoir Ck_1 form six oil pools in the highest parts of the elevations. The pools are small and the total oil-saturated thicknesses of the traps do not exceed 4 m (Figure 47).

Investigation of Stratal Liquids and Gases

Knowledge of the physicochemical properties of stratal liquids and gases, along with study of distinctive features of the structure of strata is an indispensable condition for the selection of rational systems for the development of an oil deposit. In recent years special attention has begun to be given to the investigations of stratal oils, when it has become clear that many oils display anomalous structural and mechanical properties.

Consideration of those properties is necessary in the planning and regulation of development not only for correct forecasting but also to fulfil the basic conditions for rational development.

The investigation of stratal oil, water and gases starts from the moment of testing the first wells on the area. To obtain a "clean" sample with preservation of the stratal conditions, it is necessary to have careful preparation of the well, sufficiently long drainage of the reservoir and the use of hermetic sampling devices with a capacity of several liters. Since such requirements are not always successfully satisfied under field conditions and the sampling takes a long time, the number of samples of stratal oil and water is very limited in most cases. Still the field geologist must strive to have all objects, the main reservoirs and various sections of the pools characterized by samples of oil and water taken under stratal conditions.

Observation of the variation of fluids in the process of development permits monitoring the movement of oil through the reservoir. At the same time, if we know the mechanisms and factors of change of the properties of oils in the process of development, we can, by acting on those factors, direct the process of development toward increase of the completeness of development of the pools.

Investigations conducted in recent years at the Romashkinskoye, Tuymazinskaya and other large deposits have established the principal mechanisms of change of the properties of oils and waters within pools and over the section of a deposit. Let us examine those mechanisms, using data on the Arlanskoye deposit.

According to analyses of deep samples in pools of reservoir C-VI there are the following values of the oil parameters. The oil density at the saturation pressure varies from 0.872 to 0.888 g/cm^3 and is 0.877 g/cm^3 on the average, the viscosity varies from 14.2 to 28.2 cP at a mean value of 18.2 cP, the gas factor from 15.2 to 19.6 m^3/ton with an average of 17.5 m^3/ton, and the saturation pressure from 69 to [illegible] kgf/cm^2, with an average of 86 kgf/cm^2.

The density of the degassed oil varies from 0.888 to 0.9010 g/cm^3 and is 0.89 g/cm^3 on the average; the viscosity at 20°C fluctuates from 29.4 to 39.4 cP.

In wells on the limb of the structure in a water-oil zone, increased values of the density and viscosity of oil are observed in comparison with wells in the vaulted part (Table 10).

The oil density on the Novokhazinskaya area at the saturation pressure varies from 0.880 to 0.889 g/cm^3, with a mean value of 0.886 g/cm^3; the viscosity varies from 19.1 to 32.8 cP, with a mean value of 26 cP; the density of the degassed oil varies from 0.892 to 0.902 g/cm^3. The viscosity is 47.8 cP. The gas factor varies from 12.0 to 15.7 m^3/ton and is 13.8 m^3/ton on the average, and the saturation pressure varies from 70.8 to 80 kgf/cm^2 and is 76.3 kgf/cm^2 on the average.

The qualitative characteristics of oil of reservoir C-VI of the Novolhazinskaya area is also determined by the arrangement of the wells on the structure. The oil density and viscosity are lower in the vaulted part.

Table 10 Characteristics of oils of reservoir C-VI

1 Местоположение скважины на структуре	2 Плотность при давлении насыщения, г/см³	3 Плотность разгазированной нефти, г/см³	4 Вязкость при $P_{нас}$, сП	5 Вязкость разгазированной нефти 20°С, сП
6 Арланская площадь				
7 Свод	0,872—0,875	0,888—0,8920	15,2—16,8	29,4—34,0
8 Крыло	0,878—0,879	0,810—0,8930	16,8—28	35—39
9 Новохазинская площадь				
7 Свод	0,880	0,892	19,1	35,2
8 Крыло	0,880—0,889	0,897—0,902	24,0—32,8	45,7—58,0

Key:
1 -- Well location on structure
2 -- Density at saturation pressure, g/cm^3
3 -- Density of degassed oil, g/cm^3
4 -- Viscosity at saturation pressure, cp
5 -- Viscosity of degassed oil at 20°C, cp
6 -- Arlanskaya area
7 -- Vault
8 -- Limb
9 -- Novokhazinskaya area

Oils of reservoir C-VI of the Novokhazinskaya area are denser, more viscous and less gas-saturated and have relatively low values of the saturation pressure (Table 10).

Oils of lenticular reservoirs (C-IV, C-V, C-IV^0 and C-1) differ from those of the main producing reservoirs C-II and C-VI in their lower density and viscosity, both at the saturation pressure and when degassed.

The physical indicators of oil of reservoirs C-III, C-II and C-I of the Arlanskaya area are similar: the oil density at the saturation pressure varies from 0.875 to 0.879 g/cm^3, the pressure from 72.5 to 80 kgf/cm^2, the gas factor from 17.1 to 17.9 m^3/ton, the density of the degassed oil from 0.891 to 0.893 g/cm^3, the viscosity of the degassed oil at 20°C from 34 to 37.2 cp, the volumetric coefficient from 1.045 to 1.049 and the nitrogen content from 5.7 to 6.3 m^3/m^3.

For reservoir C-II of the Novokhazinskaya area the oil density and viscosity at the saturation pressure vary from 0.867 to 0.879 g/cm^3 and from 13.9 to 22 cp, the saturation pressure from 71 to 82 kgf/cm^2, the gas factor from 15.3 to 19.2 m^3/ton, the density and viscosity of the degassed oil from 0.886 to 0.894 g/cm^3 and from 30.1 to 39.9 cp respectively.

Thus the oil of reservoir C-II of the Novokhazinskaya area differs from that of reservoir C-VII in its characteristics.

The stratal oils of the Nikolo-Berezovskaya area are similar to those of the corresponding reservoirs of the Arlanskaya area, differing from them only by lower gas-saturation and lower saturation pressure.

The deposits confined to terrigenous sediments of the Lower Carboniferous of Bashkiriya (the Charaul'skoye, Or'yebashskoye, Chetyrmanskoye, etc), located north and northeast of the Arlanskoye, have oils which in their characteristics under surface and stratal conditions are analogous to the oils of the Novokhazinskaya area, and the Mancharovskoye, Tuymazinskoye and other deposits situated southwest of the Arlanskoye have oils similar to those of the Arlanskaya area.

The principal parameters of oils of the Aleksinskiy and Tul'skiy horizons of the Nikolo-Berezovskaya area and the Tul'skiy and Bobrikovskiy horizons of the Arlanskaya area are similar in value.

Casing-head gases of oil pools confined to the terrigenous formation of the Lower Carboniferous of the Arlanskoye deposit are wet and contain light benzine fractions. Casing-head gases consist of an incombustible part, nitrogen, and a combustible hydrocarbon part. Methane and propane are predominant among casing-head gases. The quantity of butanes and pentanes + higher varies over the deposit from 11.6 to 16.8% mol. The nitrogen content in the casing-head gases of the Arlanskaya area amount to 46.5 percent on the average, and of the Novokhazinskaya to 43.05 percent. The gas density in air over the deposit varies from 1.116 to 1.250-1.277 (at a mean value of 1.185 for the Arlanskaya area and 1.216 for the Novokhazinskaya). Along with nitrogen, casing-head gases contain helium and argon. The helium content varies from 0.019 to 0.03 percent by volume.

The density of surface oil in different reservoirs for the Arlanskoye deposit varies from 0.881 to 0.915 g/cm^3, and the viscosity from 23 to 96 cp.

Heavier and more viscous oils are noted in reservoir C-VI of the Novokhazinskaya area: the oil density is 0.900 g/cm^3 on the average at a viscosity of 54 cp. At reservoir C-II of the Novokhazinskaya area the viscosity decreases to 38.2 cp at a density of 0.892 g/cm^3.

The content of tars and asphaltenes is very inconstant and fluctuates over the deposit from 14.2 to 20 percent and from 4.2 to 8.9 percent; a larger content of them is noted in oils of the Novokhazinskaya and Nikolo-Berezovskaya areas. The paraffin content varies from 1 to 4.5 percent, and of sulfur from 2 to 4 percent. In composition the oils of those areas are heavy, high-sulfur, high-tar and paraffin oils.

Distinctive features of the movement of oil over the reservoir can be judged by change of the optical properties of the oil. The optical properties of oil are determined most often by the coefficient of light absorption (k_{1a}), which reflects the content of asphaltic and tarry substances in the oil [15].

Reduction of the coefficient of light absorption of oils of the pool of reservoir C-VI on the Ashitskiy section were established by investigations on the Arlanskaya area in the first stage of development (1961-1963). It was explained by losses of asphaltenes from the composition of the oil in the process of its movement over the reservoir. A regular reduction of k_{1a} from the vault to the limb of the structure was noted in that case. The values of the coefficient varied in 1961 from 382 to 878 units, in 1962 from 311 to 642 units and in 1963 from 295 to 527 units. On one and the same areas of the Ashitskiy section there occurred a gradual replacement of the relatively low values of k_{1a} by increased values of it in time. The differences between the minimal and maximal values of k_{1a} was 496 units in 1961, 331 units in 1962 and 232 units in 1963.

Detailed field geological analysis permitted establishing the following: 1) the initial values of k_a under the conditions of the Arlanskoye deposit change in the direction of increase from the limb to the vault of the structure; 2) each oil pool in a multireservoir deposit has its own values of k_{1a}, and so the given values of k_{1a} must be studied within the limits of reservoirs of the same type; 3) at the Arlanskoye deposit the k_{1a} of the upper producing reservoirs has a smaller value than that of the lower reservoir (C-VI) within the limits of the same section; 4) when there is combined perforation of all the producing sandy reservoirs the value of k_{1a} will depend on the share of the section in the work of each reservoir.

Investigations of k_{1a} during 1965-1970 on the Novokhazinskaya area showed that for reservoirs of the same type on all sections in the course of time a stabilization or insignificant reduction of the value of k_{1a} is observed in the initial period of development, which on separate sections is a period of time of up to 5 years (as on the Ashitskiy section), and later--regular increase of the coefficient. This is also observed for jointly perforated reservoirs. However, change of k_{1a} in the latter is more complicated.

Increase of k_{1a} usually is linked with the displacement of oil from the region at the contour, where under natural conditions those coefficients have a high value. In the practice of development of the Arlanskoye oil deposit a relative increase of the coefficient is noted in all wells regardless of their position on the structure in a certain stage. In wells situated in the vault part, increase of k_{1a} in the course of time also is regular and constant, although the oil cannot reach there from the region at the contour.

This evidently also is connected with change of the properties of the oil in the process of its movement toward the bottom hole of the well.

Hydrogeological investigations are an indispensable part of the field geological study of an oil deposit. When stratal extra-contour, bottom and pumped fresh and waste waters are introduced into an oil pool, complex physicochemical changes of their composition occur. Study of the chemical composition of the waters in the process of development permits establishing the sources of the flooding of wells, clarifying the reasons for entrance of difficultly soluble sediments at the bottom holes of operating wells and solving a number of other problems.

Hydrogeological investigations are being successfully applied at the Arlanskoye oil field. The oil pools confined to different reservoirs of the large multireservoir deposit differ substantially in their structure. One of the main differences, along with others, of large oil pools confined to different reservoirs can be considered the presence of contact with bottom and stratal waters. Pools with broad water-oil zones and the presence of contour waters are confined mainly to the lower reservoir. The waters of the lower reservoirs are natural sources of flooding the production of many wells.

In the terrigenous formation of the Lower Carboniferous the sandy and sandy-siltstone reservoirs that are divided by layers of argillites and clayey shales, representing a local confining stratum and broken down into marginal and lowered parts of the structure, are water-bearing. The sandstones of reservoir C-VI are a high-pressure horizon. In view of the sharp lithological variability of the reservoir rocks and the very gently sloping descent, the waters confined to other reservoirs are stagnant and unpressurized.

On the whole the stratal waters of the terrigenous formation of the Lower Carboniferous of the Arlanskoye deposit are of the chloride-calcium type, the chloride group and the sodium subgroup and have the formula $S_1S_2A_2$. Predominant in the saline composition of the waters are sodium and potassium chlorides, which form the first salinity, the amount of which fluctuates in the range of from 78 to 86%-equivalent.

The mineralization of the stratal water over the deposit varies from 800 to 810 mg-equiv/100 g, and the density from 1.180 to 1.182 g/cm^3 respectively. The waters of the terrigenous formation of the Arlanskaya and Novokhazinskaya areas differ substantially in sulfate-ion concentration: on the Arlanskaya area in most wells the SO_4'' ion concentration is less than 1.0

mg/equiv/100 g (0.5 mg-equiv/100 g on the average), on the Novokhazinskaya the SO_4'' ion concentration in most cases exceeds 1 mg-equiv/100 g, but at times it is 1.2 to 1.8 mg-equiv/100 g. The concentrations of trace elements in waters of the terrigenous zone are the usual ones for solutions of the given saline composition and have been determined in the following quantities: 270-530 mg/liter of bromine, 1-6 mg/liter of iodine, 60-100 mg/liter of ammonia and about 1520 mg/liter of potassium. The calcium content is slightly more than twice as large as that of magnesium. The mean magnesium content in the waters varies from 2.4 to 3.2%-equivalent.

The calcium concentration varies from 3.5 to 6.2%-equiv on the average. The waters of the Novokhazinskaya area on the average have a somewhat larger concentration of calcium (4.9%-equiv instead of 4.2%-equiv on the Arlanskaya area.

The coefficient of metamorphization varies from 2.1 to 3.7.

In the analysis of the development of the deposit, to study the character of the flooding, about 1350 analyses of waters obtained in the process of surveying and developing the deposit were used. There main groups of water were distinguished: stratal, fresh and waste.

To study the chemical composition of the waters and the main hydrochemical indicators of the stratal waters, 185 analyses were used, taken from 149 wells, a large portion of which are in reservoir C-VI (111 wells). The waters of reservoir C-VI are classed in three groups: extra-outline, bottom and waters of closed sections within a pool (Table 11).

Bottom waters have some differences in individual areas (for example, a higher content of sulfate-ion is noted on the Novokhazinskaya area), but in general are similar to one another and differ little from waters of the extra-outline region.

A different picture is observed with respect to analyses of waters taken within close sections inside a pool (stagnant waters). The waters of reservoir C-VI of the Novokhazinskaya area are distinguished especially sharply in comparison with extra-outline and bottom waters and even the waters of closed sections of the Arlanskaya area: the mean density increases to 1.182 g/cm^3 (1.77 g/cm^3 on the Arlanskaya area), the mineralization to 800 mg-equiv/100 g (807 mg-equiv/100 g on the Arlanskaya area), the sulfate-ion content to 1.71 mg-equiv/100 g (0.88 mg-equiv/100 g on the Arlanskaya) and calcium to 43.5 mg-equiv/100 g (41.2 mg-equiv/100 g on the Arlanskaya).

On such sections the lower part of the reservoir is saturated with stagnant waters that are considerably removed from the main external contour of the pool, have a closed character and, probably, can be characterized as well waters. Such sections have different dimensions, the waters in them are unpressurized and they differ from bottom and extra-outline waters in their mineralization, metamorphization and content of individual components.

Table 11. Chemical composition of the waters of reservoir C-VI

Воды 1	Площади 2	Количество отобранных проб 3	Количество исследованных скважин 4	Плотность, г/см³ 5	Минерализация, 6	SO_4^{2-}	Ca^{2+}	Cl^{1-}	HCO_3^{1-}	Mg^{2+}	$K^{1+}+Na^{1+}$	Насыщенность сульфатом Ca^{2+} (гипсом), % 7
					мг-экв/100 г 8							
Законтурные 12	Арланская 10	59	58	1,172	784	0,91	38	399,2	0,16	19,7	345,4	46
	Новохазинская 11	32	18	1,181	769,6	0,92	37,8	391,5	0,09	19,7	339,2	45
Подошвенные 13	Арланская 10	7	7	1,179	793	0,45	38	401	0,18	20,3	346,3	23
	Новохазинская 11	29	18	1,181	768	0,63	35,9	395,03	0,13	19,6	340,3	28
Замкнутых участков 14	Арланская 10	5	5	1,177	807	0,88	41,21	394,3	0,12	24,6	335,7	48
	Новохазинская 11	7	5	1,182	800,4	1,71	43,50	398,9	0,19	21,4	336,7	90

Key:
1 -- Waters
2 -- Areas
3 -- Number of samples taken
4 -- Number of wells investigated
5 -- Density, g/cm^3
6 -- Mineralization
7 -- Saturation with calcium sulfate (gypsum), %
8 -- mg-equiv/100 g
9 -- not used
10 -- Arlanskaya
11 -- Novokhazinskaya
12 -- Extra-outline
13 -- Bottom
14 -- of closed sections

On the Novokhazinskaya area in the pools of reservoir C-VI such sections are confined mainly to the gently sloping eastern limb of the structure.

In addition, under the conditions of a heterogeneous structure of the section, in the absence of a connection between the zones of development of sandstones and the region of alimentation, on individual sections of a pool with a high hypsometric position water-bearing pillars remain, determining an anomalous position of the water-oil contact surface. Similar sections have been encountered in reservoir C-II of the Novokhazinskaya area.

Waters also were taken which had accumulated at the bottom holes of oil wells situated in an intra-outline dry zone. An example can be waters taken in wells 4622, 3201 and 4038 after 6 to 8 years of dry operation. In well 4622 the waters were taken 3 months before the start of flooding with pumped waters (July and August 1972). Well 4038 worked without water for 8 years and 5 months, and by the date the water sample was taken the total taking of oil had reached 8069 tons, and of water--50 m^3.

According to the main hydrochemical indicators the waters of wells 3201 and 4038 are similar to waters of closed sections of reservoir C-VI. Their mineralization amounts to 779.06-789.04 mg-equiv/100 g, the sulfate-ion content is 1.75-1.89 mg-equiv/100 g and the calcium content is 36.47-39.69 mg-equiv/100 g.

The waters of well 4622 have very high sulfate-ion contents (2.36-2.55 mg-equiv/100 g) and in mineralization and calcium content they are similar to the waters of closed sections. In our opinion they are combined waters which during operations have become mobile and accumulated in a small quantity at the bottom holes of wells.

The above presented characteristics of the waters contained in an oil pool are of interest from the point of view of study of the "primary" geological prerequisites for the precipitation of difficultly soluble sediments at the bottom holes of producing wells (in particular, of gypsum at isolated sections of the Novokhazinskaya area).

According to the data of B. V. Ozolin [43], the solubility of calcium sulfate in natural brines can be judged approximately with the semi-empirical dependence

$$C_{SO_4} = \frac{108}{C_{Ca} d^2},$$

where C_{SO_4} and C_{CA} are the concentration of Ca^{+2} and SO_4^{-2} ions, in mg-equiv/100 g; d is the density of the solution, g/cm^3.

This formula was obtained for mineralized (more than 600 mg-equiv/100 g) and metamorphized solutions.

Table 12. Chemical composition of fresh and waste waters

Воды 1	Площади 2	Плотность, г/см³ 3	Минерализация 4	SO_4^{2-}	Ca^{2+}	Cl^{1-}	HCO_3^{1-}	Mg^{2+}	$K^{1+}+Na^{1+}$
			мг-экв/100 г 5						
Сточные 6	Арланская 7	1,04—1,069	246,8—319	0,27—0,53	7,16—15,72	102,2—159,01	0,18—0,35	6,25—8,88	109,54—146,67
	Новохазинская 8	1,0539—1,0996	248,5—446,8	1,14—7,04	13,20—21,96	107,1—220,6	0,30—0,70	6,97—11,9	82,28—139,28
Пресные 9	Новохазинская 8	1,0238—1,0590	167,65—267,4	1,10—3,62	6,61—14,42	63—117	0,26—0,46	2,91—6,82	59,91—121,70

Key:
1 -- Waters
2 -- Areas
3 -- Density, g/cm³
4 -- Mineralization
5 -- mg-equiv/100 g
6 -- Waste
7 -- Arlanskaya
8 -- Novokhazinskaya
9 -- Fresh

Calculations made with that formula showed that the extra-outline and bottom waters of reservoir C-VI of the Arlanskaya and Novokhazinskaya areas contain only 23 to 46 percent of calcium sulfate, waters of closed sections of the Arlanskaya area contain 48 percent, and waters of the Novokhazinskaya area are close to saturation (90 percent).

Waters taken from the bottom holes of oil wells after long dry operation before the start of their flooding with pumped waters (wells 4622, 4038 and 3201) consist of highly mineralized brines, near saturation and even supersaturated with calcium sulfate, and can be a source of gypsum formation in the bottom holes of operating wells.

Very favorable conditions for gypsum precipitation are created in zones hwere the waters have an unpressurized closed character, and also in reservoirs that have a low initial oil saturation.

During movement through the reservoir, fresh waters pumped in the process of development and waters of field runoffs change their chemical composition (Table 12). The main reasons for that change are the different quantitative and qualitative characteristics of the combined water during intra-outline flooding and of stratal water during extra-outline vlooding, and also difference of the chemical composition of the pumped waters.

Knowledge of the chemical composition of these waters helps to determine the sources of flooding of wells and also facilitates interpretation of radiometric measurements during the monitoring of the movement of waters in reservoirs.

Chapter 5. Questions of Procedure in Estimating Oil and Gas Reserves

Field geological study in the process of the organization of a deposit is reduced to refining the main distinctive features of the geological structure of the deposit. In the course of mass drilling of wells the complex relief of the surface of sandy and carbonate traps is revealed and additional information is received about the distribution of the thicknesses of traps and their lithological-physical characteristics. This information must be studied in order to determine more precisely the volume of oil reserves for the deposit as a whole and the character of their distribution by pools, isolated sections of pools, reservoirs and members.

To judge by experience in the surveying and development of large oil deposits (the Romashkinskaya, Tuymazinskoye, Arlanskoye, etc), usually even a sparse network of survey wells permits determining the main distinctive features and regularities in the structure of a deposit and estimating the oil reserves of the deposit with an accuracy of within ± 5 to 12 percent. A sharp change in the quantitative estimate of oil reserves (25 to 45 percent) when additional geological information is obtained can most often be caused, not by change in the concepts of the geological structure of the deposit (pool), but by an improperly selected method of estimating oil reserves or the application of various methods in the initial and subsequent estimation of the oil reserves. A special role is played in this by the procedure in estimating the oil-saturated volume of the traps.

Methods of Determining the Volumes of the Oil-saturated Part of a Reservoir

It is extremely important that as precise and reliable as possible values of the oil and gas reserves be obtained even in the first calculations. Besides the extent to which the object has been studied, the quantity and quality of the starting data, the procedure for determining the volumes of the oil-saturated rocks has a great influence on the precision of the calculations.

Usually the volume of the oil-saturated rocks is determined from a map of the effective thickness of traps by calculating the elementary volumes and subsequently summing them according to the formula

$$V = f_1 h_1 + f_2 h_2 + \ldots + f_n h_n,$$

where V is the reservoir volume, in m^3; f_1, f_2, f_n are the areas of the sections between two adjacent isopachous lines, in m^3; h_1, h_2, h_n are the mean oil-saturated thickness, in m, determined as the half-sum of the adjacent isopachous lines.

In constructing a map of oil-saturated thicknesses the principle of interpolation in zones of tapering off and replacement of oil-saturated traps is important. Two methods of interpolation of thicknesses, the linear and the nonlinear, are usually used. In the linear interpolation the zero isopachous line is drawn through the well and the revealed zero thickness of the trap, and in the nonlinear -- at the middle distance between the "zero" and the nearest wells that have revealed the reservoir rock. The amount of the relative divergence between the rock volumes calculated by the two methods is mainly determined by the density of the network of wells, the effective thickness of the trap on the outer boundaries of the zones of replacement or tapering off and the total perimeter of the latter.

Substantiated selection and systematic observation of one of the principles in that case give confidence in the reliability of the calculated volume of oil-containing rocks.

Under the conditions of multireservoir deposits the amounts of the volume of rocks can be calculated in two ways: by the sum of the volumes of individual reservoirs according to maps of the corresponding reservoirs and according to the map of the total oil-saturated thickness of that section as a whole.

With the first method the task is reduced to determining the volumes of single-reservoir deposits (the number of which will depend on the number of producing reservoirs in the section and their isolatedness on the area) and summing them. The method of linear and nonlinear interpolation can be used to achieve that.

With the second method only the linear method of interpolation is used, since in multireservoir deposits the zones of replacement and tapering off of individual reservoirs, as a rule, do not coincide in the plane, which on the map of total thicknesses leads systematically to the displacement of zero thicknesses on individual reservoirs at the point of the nearest wells. A false picture is created of the continuity of actually discontinuous reservoirs, and this leads to increase of the area of propagation and their oil-saturated thickness and, consequently, also of the volume. Through nonlinear interpolation this overstatement of the volume obtained according to the map of total thicknesses (from the data of V. A. Bad'yanov) can reach 25 percent.

With the second method a considerable divergence in the rock volumes can also be connected with the position of the oil pool outlines of superposed reservoirs independently of the lithological discontinuity of the traps. The difference in volumes obtained by the different methods amounted to 24 percent in terms of the oil and gas reserves on the Arlanskaya area.

The boundaries of the oil pools of reservoirs C-II and C-VI and their oil-saturated thicknesses were established from data on 600 wells (1964). Geological and geophysical data were studied with consideration of studies of core material and samples of rocks taken with a lateral sampling device, and also the results of testing and operation. The number of wells in which reservoir rocks C-II and C-VI have been replaced by dense rocks is relatively insignificant (15 and 13 percent of the number drilled). The volumes of oil-saturated rocks in the total volumes of all reservoirs when calculated separately amount to 40 and 31 percent. In constructing maps of the thicknesses of sandstones of traps the middle distances between adjacent wells were taken as the zero line of their propagation during displacements.

The percentage of wells in which thin reservoirs were found in a sandy facies (C-I, C-III, C-IV^0, C-IV, C-V and C-VI^0) on the area does not exceed 50 out of the total number of wells drilled. However, the sum of the rock volumes of those reservoirs amounts to less than 30 percent of the total sum of oil-saturated volume of all the reservoirs.

To explain the difference in the volumes of rocks obtained on account of use of different methods of interpolation, on reservoir C-VI a map was constructed of the oil-saturated thickness with a zero isopachous line passing directly through the well, and not at the middle distance between the closest wells. Instead of zones of displaement and "spots", lines of displacement and zero points were obtained. The divergence in the volumes of rock calculated with those maps proved to be 1.9 percent, which corresponds to the limits of the allowable error of planimetry.

On the maps constructed for reservoir C-II by different methods we obtain an increase of 3.5 percent of the volume of the reservoir obtained by the method of drawing the zero isopachous line at the middle distances between the closest wells. Thus the divergence of the volumes also lies within the limits of the allowable error.

The difference in volume obtained from the map of total oil-saturated thicknesses of the sandy reservoirs C-I + C-II + C-III and the total volume of reservoirs C-i, C-II and C-III proved to be 9 percent.

Very often the divergences in volumes are not connected with the method of interpolation. Near the boundaries of replacement of traps their thicknesses are sharply curtailed, and therefore the volumes of rocks calculated by the different methods differ insignificantly for individual thin reservoirs.

The divergence of volumes is connected more often with an unusual position of the oil pool outlines of individual reservoirs. In our exammple the oil pool of reservoir C-VI, in contrast with all others, has an extensive water-oil zone. The perimeter of the outer oil pool outline of ten oil pools of reservoir C-VI on the Arlanskaya area amounts to over 180 km. The oil-bearing areas of the above-lying reservoirs are far greater than the oil-bearing area of reservoir C-VI, since they occupy a higher position on the structure. Summation of the thicknesses of the upper reservoirs leads to

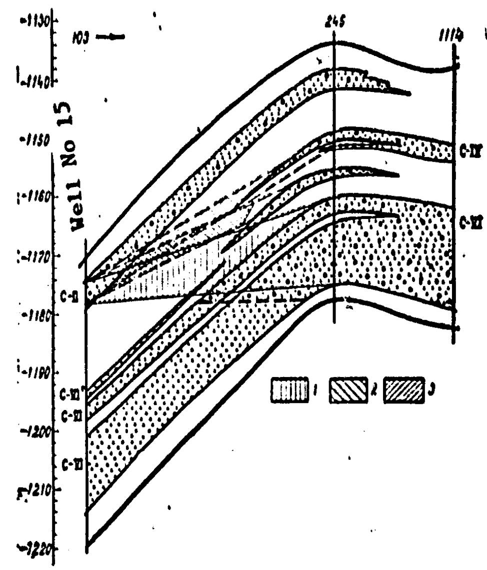

Figure 54. Schematic geological profile of the Arlanskaya area. Increment of volume: 1 -- for reservoir C-VI; 2 -- for reservoir C-V; 3 -- for reservoir C-IV.

expansion of the oil-bearing area of reservoir C-VI to the nearest operating wells in which the covering reservoirs consisted of a trap (Figure 54). The distance between the wells plays a large role here.

On the Arlanskaya area during expansion of the oil pool outline of reservoir C-VI (at a thickness of 8 to 12 m), gradually in relation to the outlines of all the above-lying reservoirs, with a corresponding increase of thickness and oil-bearing area for each of them, for reservoir C-II a weighted mean thickness of 3.2 instead of 2.5 m was obtained, and for reservoir C-VI 5.9 instead of 4.4 m. Consequently, such a method leads to a considerable overstatement of the volume for the given conditions.

Thus under the conditions of a multireservoir deposit, where the separate reservoirs have a sharp difference in thicknesses, contours and oil-bearing areas, the maps of total oil-saturated thicknesses distort our concepts of the structure of the oil pools.

The study of the geological structure of multireservoir deposits similar to the Arlanskoye for purposes of analysis of the development and calculation of oil and gas reserves should be done separately by reservoirs.

Comparative Analysis of the Volumes of Oil-Saturated Rocks Obtained at Different Densities of the Network of Wells

The new geological information about separate areas, obtained during the drilling of deposits, is used not only to explain details of the geological structure of numerous oil pools. More precise determination of the volumes of oil-saturated rocks has acquired very great importance. At the Arlanskoye deposit, for comparative analysis of the volumes of pools at different densities of the network of wells, maps were constructed of the oil-saturated thicknesses by nonlinear interpolation for separate reservoirs from data obtained in exploratory drilling. The same maps were constructed with consideration of the information, which has increased by 10-15 times on the basis of data obtained by operational drilling.

Presented below is a comparative analysis of the changes obtained on account of lithological and structural factors for different reservoirs and areas.

Reservoir C-VI. The oil pools confined to reservoir C-VI differ considerably in geological structure on different areas. For example, on the Arlanskaya area the oil pools are narrow and linearly extended. Over 50 percent of the oil reserves are concentrated in water-oil zones, etc.

As a result of obtaining additional geophysical information for comparison with survey data the total oil-bearing area of oil pools of reservoir C-VI (with consideration of the structural position and the water-oil contact on marginal sections and inside the pool) on the Arlanskaya area was reduced by 16.9 percent and on the Novokhazinskaya by 7.5 percent, and through enlargement of the zones of lithological replacement within the outline, by 2.7 and 3.5 percent respectively (Figure 55).

In addition, for pools of reservoir C-VI of the Arlanskaya area a reduction of the weighted mean oil-saturated thickness by 16 percent is observed, and an increase of it by 0.2 percent on the Novokhazinskaya. On the whole for reservoir C-VI of the Arlanskaya area the change of volumes is very considerable (35 percent), and 10.8 percent for reservoir C-VI of the Novokhazinskaya area.

A different picture is observed with respect to pools confined to reservoirs of the Tul'skiy horizon. They differ greatly in their structure from pools reservoir C-VI: they are found in favorable structural conditions (as a result of which the volumes of soil-saturated rocks in water-oil zones does not exceed 5 percent). In producing reservoirs, sharp facial variability of the traps was noted (with the exception of reservoir C-II).

The main share of the oil-saturated volume of the rocks (71-96 percent) is concentrated in pools of the Tul'skiy horizon.

When the network of wells is densified to the planned degree for separate reservoirs, a reduction of the oil-bearing areas is noted in the main: from

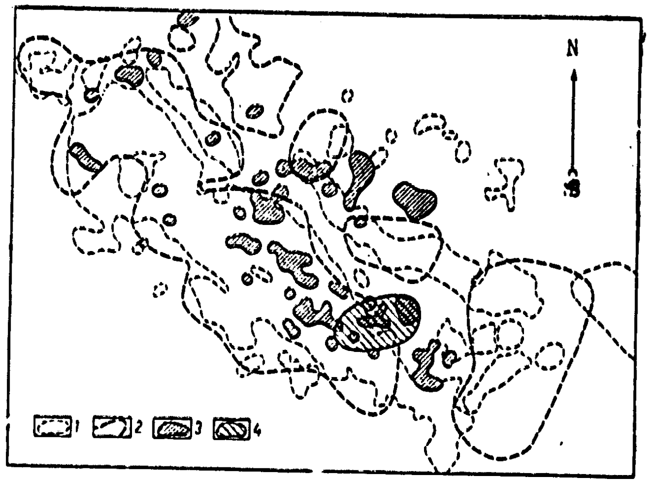

Figure 55. Positions of the oil pool outlines of reservoir C-VI of the Arlanskaya area.
1 -- outer oil pool outline of reservoir C-VI according to operational drilling data;
2 -- ditto, according to exploratory drilling data;
3 -- zones of trap replacement according to operational drilling data;
4 -- ditto, according to exploratory drilling data.

3 (reservoir C-II of the Novokhazinskaya) to 44 percent (reservoir C-I of the Nikolo-Berezovskaya). Increase of the oil-bearing area is observed only in certain cases: reservoir C-V of the Novokhazinskaya by 5.7 percent, reservoir C-V of the Nikolo-Berezovskaya by 31 percent and reservoir C-VI^0 of the Arlanskaya area by 292 percent.

For reservoir C-II the oil-bearing area was reduced on the outer outline by 10 percent on the Arlanskaya and Nikolo-Berezovskaya areas, and on the Novokhazinskaya increased by 5 percent.

Zones of dense rocks (lithological "windows") in the oil pool outline were increased by 7-8 percent on all areas (Figures 56 and 57). On the whole, however, on account of lithological and structural factors), a reduction of the oil-bearing area by 17-18 percent is noted on the Arlanskaya and Nikolo-Berezovskaya areas, and by 3 percent on the Novokhazinskaya, only on account of the lithological factor. However, on all the reservoirs (except C-I of the Arlanskaya, C-II of the Novokhazinskaya and C-III and C-IV of the Nikolo-Berezovskaya area) one notes an increase in the weighted mean oil-saturated thickness of the producing reservoirs (of from 2.5 to 30 percent). As a

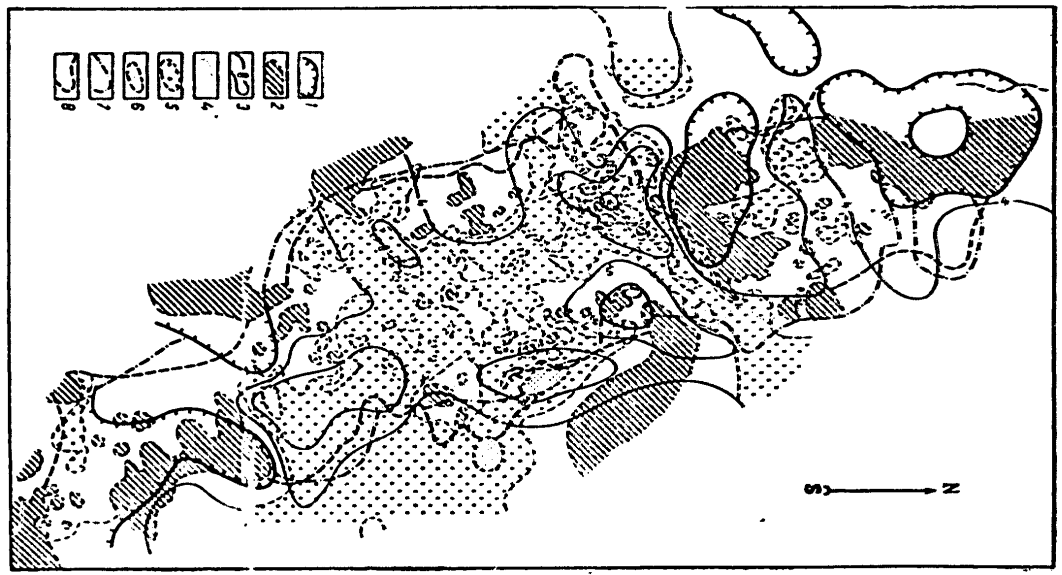

Figure 56. Diagram of development of traps of reservoir C-II of the Novokhazinskaya area. 1 -- zones of trap replacement according to exploratory drilling data;
2 -- ditto, according to operational drilling data;
3 -- isolines of thickness according to exploratory drilling data;
4 -- zones of trap distribution with thicknesses of zero to 4 m according to operational drilling data;
5 -- ditto, with a thickness of 4 to 8 m;
6 -- ditto, with a thickness of over 8 m;
7 -- outer oil pool outline according to exploratory drilling data;
8 -- ditto, according to operational drilling data.

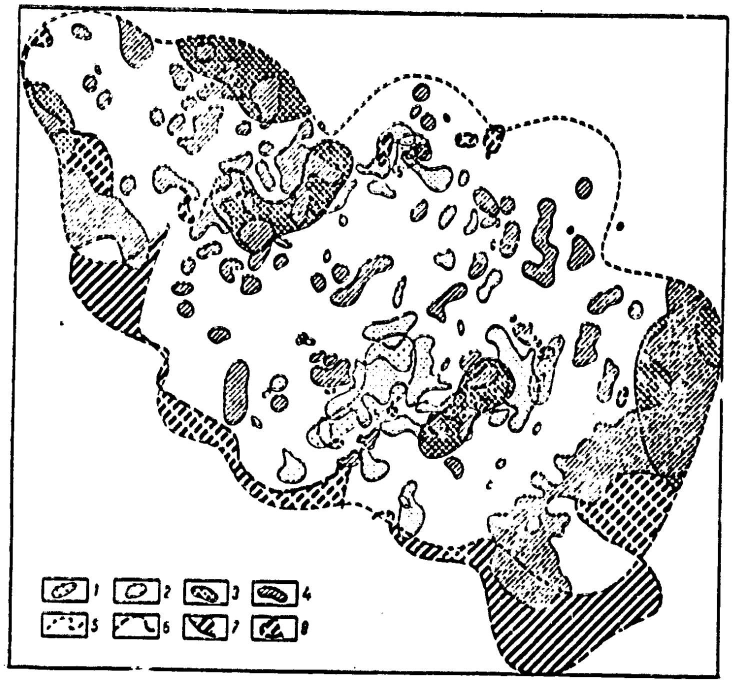

Figure 57. Diagram of development of traps of reservoir C-II of the Arlanskaya area.
1 -- sections of development of traps with a thickness of over 5 m according to exploratory drilling data;
2 -- ditto, according to operational drilling data;
3 -- sections where traps of reservoir C-II have been replaced by dense rocks;
4 -- ditto, according to operational drilling data;
5 -- outer oil pool outline according to exploratory drilling data;
6 -- ditto, according to operational drilling data;
7 -- increase of oil-bearing area according to operational drilling data;
8 -- reduction of oil-bearing area according to operational drilling data.

result, on some reservoirs an increase of volume (from 12 to 36 percent) is observed, and on others a decrease (from 4 to 36 percent), but the sum of the volumes of all reservoirs of the Tul'skiy horizon according to operational drilling data varies insignificantly (3.3 percent for the Arlanskaya and 4.0 percent for the Novokhazinskaya), and only on the Nikolo-Berezovskaya area does the reduction of volumes reach 10.8 percent.

Thus with increase of the volume of information the boundaries of the distribution of traps in dense rocks is determined much more accurately, and this has led to a redistribution of the volumes of oil-saturated rocks over different reservoirs. However, the lithological variability of the reservoirs on the Arlanskaya and Novokhazinskaya area does not exert a great influence on change of the total of the volumes of oil-saturated rocks on the whole for reservoirs of the Tul'skiy horizon. At the same time the volume is considerably reduced on account of the structural factor for pools confined to reservoir C-VI. Since the relative share of the volumes of oil-saturated rocks confined to pools of reservoir C-VI is large, the reduction was also reflected in the size of the volumes of oil-saturated rocks on the whole for the deposit. In a separate calculation of oil reserves by reservoirs on all areas of the deposit the sum of the volumes of oil-saturated rocks was smaller than according to exploratory data: by 4.1 percent on the Novokhazinskaya area, 15.2 percent on the Arlanskaya and 8 percent on the Nikolo-Berezovskaya.

The divergence of the volumes of oil-saturated rocks, determined on the Arlanskaya area from maps of the total oil-saturated thicknesses and from exploratory and operational drilling data amounts to about 10 percent. Thus under complex geological conditions of the Arlanskoye deposit the change of the total volumes of oil-saturated rocks, with use of an identical method but with different densities of the network of wells is insignificant.

Comparison of the results obtained by the different methods shows, however, that their divergence is very large on individual areas (the Arlanskaya).

Consequently the disposition of exploratory wells on profiles with distances of 2-4 km between them on the Novokhazinskaya and 2.5-3 km on the Nikolo-Berezovskaya areas should be considered correct. In estimating the oil reserves of a multireservoir deposit it is necessary to determine the volumes of the oil-saturated rocks in the very initial stage separately by reservoirs.

The Interconnnection of Heterogeneity and Oil-Saturation

The structure and permeability of the pore space of sandstones is determined not only by the form, packing and cementing of the mineral grains but also by the amount of compacting pressure [1], the result of which in turn is determined by lithological features of the reservoir trap (clayeyness, carbonateness, etc). Therefore the pore space of sandstones can be represented in the form of a network of overlapping slits. Consequently, under real geological conditions the reservoir trap consists of an anisotropic medium with a porosity and permeability that vary over both the section and the course. In addition, the complexity of the distribution of porous-permeable varieties in a producing reservoir is intensified by the presence of macroheterogeneity expressed i interstratification, rapid petering out and the replacement of clayey and other relatively impermeable layers by permeable varieties.

In the process of seepage, particles of liquid pass through a large number of chaotic distributions in space and pore canals of different sizes. The presence in the path of linearly seeping liquid of media with different permeability will be accompanied by the effect of seepage refraction with damping of oil seepage from the medium with greater into the medium with less permeability. The damping of oil seepage in a porous medium can also be caused by physicochemical phenomena. As has been established by the experimental investigations of P. A. Rebinder, M. M. Kusakov, K. Ye. Zinchenko, F. A. Trebin, G. A. Babalyan, I. L. Markhasin and G. V. Rudakov [1], the rate of seepage of oil containing polar components is reduced considerably on account of reduction of the clear opening of the pore canals as a result of adsorption of the polar components on the surfaces of quartz grains. The intensity of adsorption of those components rises with increase of their content in the oil and with increase of the specific surface of the reservoir traps and their hydrophily.

The distribution of oil saturation in an oil pool will have a rather complex picture, caused both by petrophysical features of the structure of the reservoir trap (variation of permeability, porosity, micro- and macroheterogeneity, etc) and by physicochemical phenomena that arise in the reservoir during oil seepage.

Under the conditions of a real oil pool the influence of the above-indicated petrophysical and physicochemical factors leads to a reduction of oil-saturation with approach to the zones of replacement of the reservoir rocks and to a different oil saturation of the separate sandy layers in sections where an alternation of permeable and impermeable varieties is noted. In addition, the zones (sections) of an oil pool that have a weak connection with the external region of alimentation will also have low oil saturation. Besides low oil saturation the presence of free water with an anomalous position of the water-oil interface is possible in such zones, since to fill the reservoir with oil simply high permeability of the trap is insufficient, and it is necessary that the reservoir have available paths for the emigration of water from the filled volume of the reservoir. Therefore the change of oil saturation is more sensitive to change of the lithological heterogeneity of a producing reservoir than other parameters such as the coefficient of arenosity, heterogeneity, etc.

V. M. Berezin determined under laboratory conditions the coefficient of residual initial water-saturation for seven wells of the Arlanskoye deposit. The content of residual water for separate intervals of reservoir C-II vary from 3.3 to 62.7 percent, and for reservoir C-VI-- from 10.3 to 35 percent.

For a large number of wells a determination was made of the residual water-saturation according to field geophysical data (2679 determinations). The obtained mean values agree well with the laboratory determinations based on cores.

The mean residual water content in thin clayey reservoirs is large--about 30 percent or more. This is confirmed by operating data from many wells at a deposit working thin reservoirs. A small quantity of water appears periodically in the production of those wells.

As an example of the distribution of oil-saturation we will examine oil pools in reservoirs C-II and C-VI of the terrigenous formation of the Lower Carboniferous of the Novokhazinskaya area of the Arlanskoye deposit. The oil-saturation coefficient was determined from the resistivity, with consideration of the porosity and permeability.

One of the distinctive features of terrigenous deposits of Carboniferous age as compared with terrigenous deposits of the Devonian of Shkapovskoye, Tuymazinskoye and other deposits is a high content of clayey material, which in the presence of better trap properties causes a high content of combined water. In visual study of traps of the terrigenous formation an irregular saturation of the rocks with oil is noted. Very intensive saturation is noted in very porous and permeable varieties of sandy rocks. With increase of clayeyness the oil saturation diminishes or is not noted at all. The oil saturation is also inconstant in individual layers.

The distribution of oil saturation in pools was analyzed together with maps of types of sections (Figures 28, 33), reflecting lithofacial characteristics of the structure of the producing reservoir, and maps of the coefficient of arenosity, reflecting the heterogeneity of the section. Combined analysis of those maps permitted establishing that the zones of maximum oil saturation (90 percent or more) of reservoirs C-VI and C-II correspond to the zones of development of homogeneous sandstones with maximum thickness. In the zones of development the oil saturation of only the upper part of the reservoir is reduced. In the zones of development of the lower part of reservoir C-VI, which is very developed in area and is characterized by high trap properties, the oil saturation can also reach 90 percent in individual sections of the pool. In zones of frequent interstratification or development of the upper part of reservoir C-VI the oil saturation reaches 68-78 percent. Thus, on a background of high values of oil saturation in the central part of the Novokhazinskaya area sections are noted with low values of the coefficient of oil saturation (70-80 percent). Only the upper part of reservoir C-VI is developed there in the section, although the gypsometric position of those sections is high.

The behavior of the oil saturation structure contours in general agrees with the behavior of those of the coefficient of arenosity and the development of types of sections. This is especially evident from the example of a pool confined to reservoir C-II. The reservoir is fairly well developed in the central part of the area, and only on isolated sections are its lower or upper parts replaced. The maximum values of the coefficients of arenosity and oil saturation correspond to the zones of confluence of the reservoir. However, the contour lines of equal values of the coefficient of oil saturation are displaced somewhat and the area of maximum oil saturation is somewhat smaller than the area of development of sandstones with maximum thickness. This confirms well the above-noted hypothesis of a dependence of the oil saturation on the petrophysical properties of the reservoir and the physicochemical properties of the oil.

The distribution of oil saturation is controlled to a considerable degree by the presence of a connection between the zones of development of sandstones and the region of alimentation. Thus, for example, in the northeastern part of the pool the reservoir of sandstone C-II is developed in a narrow band, extended from the northeast to the southwest. The zone of development of that sandstone is controlled by zones of complete or partial replacement. The oil saturation of sandstones in that zone is 78-82 percent and only on isolated sections does it reach 87 percent. A similar picture is observed also in the eastern part of the pool of reservoir C-II.

The absence of paths for the emigration of water when the trap is filled with oil had the result that on isolated sections of the pool with a high hypsometric position pillars of pure water remain which cause the appearance of anomalous water-oil contacts. One can cite as an example the presence of pure water in reservoir C-II in the section of well 229, situated in the vault of the elevation. The water-oil contact mark in that well is at -1137.4, that is, about 6-10 m higher than the mean position of the water-oil contact for reservoir C-II.

In isolated cases the redistribution of petroleum and water in the process of pool formation leads only to the formation of zones of high water saturation in the bottom of the reservoir.

This phenomenon is characterized by reduction of the resistivities toward the bottom of the reservoir, with the formation of transitional zones in saturation with oil in the absence of a limitingly water-saturated part of the reservoir. During testing those reservoirs, as a rule, start to work with a small percentage of water, the appearance of which is connected with its arrival directly from the reservoir, dissected by perforation, and not on account of flooding of the poor in the process of operation. Thus, for example, in well 3227 reservoir C-II is dissected in the interval 1210-1214.8 m. Electrometry reveals that the reservoir is homogeneous with a transitional zone. During leakage from the reservoir a flow of oil with 4 percent water was obtained. Similar results were obtained during the testing of wells 3719, 3256, 3715, etc, in which the producing reservoirs had a transitional zone of saturation. Reservoirs with a transitional zone in the absence of a limitingly water-saturated part are developed very widely in the pool of producing reservoir C-II.

The above-presented data permit drawing the following conclusions.

1. The distribution of oil saturation in a pool is closely connected with the petrographic features of the reservoir structure, the degree of its heterogeneity and the properties of the oils themselves.

2. Maps of oil-saturation reflect to a considerably greater degree the heterogeneity of the structure of a reservoir than do other parameters (the coefficients of arenosity, heterogeneity, etc), since the distribution of oil saturation is more sensitive to various types of structural and physical heterogeneities of the reservoir trap.

3. An important role in the distribution of oil saturation over a pool is played by the presence or absence of a connection of the reservoir trap with the region of alimentation. The absence of paths for the emigration of water from the pool as it is filled with oil determines the degree of filling of the pool with oil and contributes to the formation of zones of high water saturation in the bottom part of a producing reservoir and even isolated pillars of water, which leads to the formation of zones with anomalous water-oil contacts.

4. Knowledge of distinctive features in the distribution of oil saturation over a pool is of great importance in analyzing the development of a deposit, as it permits forecasting the process of flooding the pool and estimating the degree of its development.

Chapter 6. The Use of Geological Investigations for the Planning and Analysis of Development

Distinguishing Objects of Development

Very critical tasks of geological field investigations in planning the development of multireservoir deposits are the selection and substantiation of objects to be worked. These tasks must be solved to assure the most complete working of reservoirs possible at high rates and with the best technological and economic indicators.

Objects are distinguished in the stage of the principal (general) or technological plan of development with a small number of starting data. The need to distinguish independent objects of development or to combine the main producing reservoirs into a single object of development is substantiated by the geological field and the technological and economic indicators.

At large multireservoir deposits of Uralo-Povolzh'ye, Western Siberia and Mangyshlak (Tuymazy, Shkapovo, Mukhanovo, Samotlor, Sovetskoye, Ust'-Balyk, Uzen', etc), 2-4 objects of development with independent networks of wells have been distinguished in a producing oil-bearing section. At the Romashkinskoye and Arlanskoye deposits the main producing reservoirs are being worked jointly. The geological field characteristics of the objects of development, which influence the productivity of wells, the working of oil reserves, the flooding of pools, etc, have similar values of some parameters and differ substantially in others. At the Arlanskaya area, on an oil-bearing member of Kashiro-Podol'skoye carbonate sediments wells with an independent operational network have been drilled. The main criteria in distinguishing objects of development were the reserves and quality of the oil and the proposed development systems. In recent years in Western Siberia a trend has been designated toward the distinguishing of multireservoir objects with the largest thicknesses. Contributing to this were the assumed possibilities of simultaneous separate working of several producing reservoirs and regulation of their development through the separate pumping of water. In addition, such geological and physical factors were taken into account as the presence or absence of a hydrodynamic connection between producing reservoirs, the thickness of the section between producing formations, the seepage properties of the traps, the types and regimes of the pools and the physicochemical properties of the oils.

The variety of geological field parameters and their variability predetermine peculiarities in the structure of each object of development and the differences between them. Their similarity is manifested only in the following very general characteristics. All the comparable objects of development are distinguished at deposits confined to large elevations--folds of the platform type. The main field reserves in them are connected with reservoirs of terrigenous sandy-siltstone traps of the pore type. Considerable oil reserves are concentrated in the water-oil zones.

The differences existing between objects of development can be determined from a number of parameters and indicators.

An important indicator that characterizes objects of development is the quantity of specific oil reserves per well. This indicator to an important degree determines the selection of the development system and its profitability and can be used in comparing objects of development only when the well network density values are identical or similar. This condition is met by objects of development I and II of the Uzen' and Shkapovo deposits, where the well network density is approximately identical over the entire oil-bearing area. Comparison shows that the oil reserves per well at Uzen' objects of development are 2 to 4 times as large as at Shkapovo objects of development.

The specific oil reserves per unit of area can serve as objective indicators for comparison. The Samotlor and Uzen' objects of development have the largest specific reserves, and the Tuymazy, Shkapovo and Arlan have the smallest.

An important parameter characterizing objects of development is the weighted mean thickness of the traps (Table 13). On the deposits under consideration that parameter in its main features determines the possible productivity of the operating and pressure wells and can be determined relatively precisely from a small number of wells in the stage of compilation of a block or technological diagram. This permits comparing the thickness of the objects of development drilled with different well network density.

All objects of development can be divided into two groups on the basis of the value of the mean thickness of the traps. In the first group are placed objects of development with a relative thickness of 1 to 1.8, and in the second those with a relative thickness of 2 to 3.2 conventional units.

Included in the first group are 10 objects of development, including Shkapovo (D_I and D_{IV}), Tuymazy (D_I and D_{II}), Samotlor (A_2 - A_3), Uzen' (XVII and XVIII), Sosninsko-Sovetskoye (A_1 and B_8) and Mukhanovo (object II--reservoirs C_{II} + C_{III} + C_{IV}). Included in the same group are an object of development of the Arlanskoye deposit (C-II + C-V, etc) and a large portion of an object of development (D_1) of oil field areas of the Romashkinskoye deposit with the exception of its central part.

The second group includes six objects of development: Samotlor (A_{4-5} and B_8), Uzen' (XIII + XIV and XV + XVI) and Mukhanovo (C_I) and D_I + D_{II} + D_{III} + D_{IV}. In addition, objects of development of the Abdrakhmanovskaya area of the Romashkinskoye (D_I) and Ust'-Balykskoye (B_1 + B_{2-3} + B_4) deposits can be included in the second group for their large thicknesses.

Table 13. Characteristics of oil pools of some deposits

Месторождение, площадь [1]	Объекты разработки [2]	Продуктивные горизонты [3]	Мощность коллектора объекта разработки, усл. ед. [4]	Количество нефтяных пластов в объекте разработки [5]	Коэффициент расчлененности объекта разработки [6]	Проницаемость, мД [7]	Вязкость пластовой нефти, сП [8]	Плотность пластовой нефти, г/см³ [9]	Содержание асфальтенов и смол, % [10]	Содержание парафина, % [11]
15 Шкаповское	I	$Д_I$ [12]	1,2	До 6 [13]	2,1	360	4,0	0,83	14,9	4,5
	II	$Д_{IV}$	1,0	До 6	2,4	310	0,95	0,74	7,7	6,0
16 Новохазинская		C-II+C-VI и др. [14]	1,2	До 8	3,2	90—1500	18,0	0,88	22,4	2,1
17 Туймазинское	I	$Д_I$	1,3	До 5	1,9	370	2,3	0,8	13,0	4,5
	II	$Д_{II}$	1,7	До 3	1,5	210	2,3	0,8	13,2	5,1
18 Мухановское	I	C_{-I}	2,6	До 6	3,6	930	2,7	0,81	8,9	7,5
	II	$C_{II}+C_{III}+C_{IV}$	1,7	До 9	6,0	230—440	3,0—5,8	0,78—0,82	6,0—11,5	3,4—8,8
	III	$Д_I+Д_{II}+Д_{III}+Д_{IV}$	2,0	До 10	7,0	30—190	0,6—2,3	0,62—0,71	1,7—6,2	4,6—6,5
19 Абдрахмановская		$Д_I$	2,6	До 7	4,2	230	3,0	0,86	3,4	3,4
20 Соснинское-Советское	I	$А_I$	1,6	До 9	5,4	70	1,5	0,78	11,1	2,9
	II	$Б_8$	1,1	До 5	2,8	490	1,1	0,74	8,5	2,6
21 Самотлорское	I	$А_4+А_3$	1,8	До 15	9,0	380	1,4	0,78	10,1	2,9
	II	$А_4+А_6$	3,0	До 24	11,0	450	1,9	0,79	9,8	2,7
	III	$Б_8$	3,2	До 19	9,8	550	1,0	0,74	9,5	2,9
22 Узеньское	I	XIII+XIV	2,5	До 25	11,7	350—220	4,0—3,4	—	—	—
	II	XV+XVI	2,0	До 18	6,8	200—150	3,4—3,5	—	—	—
	III	XVII	1,8	До 8	4,0	190	3,6	0,77	17,7	15,8
	IV	XVIII	1,3	До 10	7,3	100	3,6	—	—	—

Key: See next page.

Table 13 (Key)

1 -- Deposit, area
2 -- Objects of development
3 -- Producing horizons
4 -- Thickness of traps of object of development
5 -- Number of oil reservoirs in object of development
6 -- Coefficient of breakdown of object of development
7 -- Permeability, mD
8 -- Viscosity of stratal oil, cp
9 -- Density of stratal oil, g/cm^3
10 -- Asphaltenes and tar content, %
11 -- Paraffin content, %
12 -- D_I
13 -- Up to 6
14 -- etc
15 -- Shkapovskoye
16 -- Novokhazinskoye
17 -- Tuymazinskoye
18 -- Mukhanovskoye
19 -- Abdrakhmanovskaya
20 -- Sosinskoye-Sovetskoye
21 -- Samotlorskoye
22 -- Uzen'skoye

It follows from the comparison that most of the objects of development belong to the third group on the basis of the trap thickness. Attention is attracted by the fact that the thickness of traps of some large objects of development of Uralo-Povolzh'ye, for example, Shkapovo (D_I and D_{IV}) and Tuymazy (D_I) is one-half to one-third as large as the same parameter in larger objects of development of Samotlor (A_{4-5} and B_8), Uzen' (XIII + XIV and XV +XVI) and Ust'-Balyk ($B_1 + B_{2-3} + B_4$).

From experience in the development of large multireservoir deposits of Uralo-Povolzh'ye it is known that the productivity of wells, the rates of development, the inclusion of reservoirs according to thickness, etc, are in a direct dependence on not only the thickness of the object but also the lithological heterogeneity of producing reservoirs.

Objects of development usually consist of an interstratification of reservoir rock of various thickness and permeability and the dense rocks bedded between them. Therefore it is correct to compare them by means of different coefficients reflecting the geological heterogeneity of all the pools constituting the object of development.

Used for a comparative estimation of the heterogeneity of the lithological structure was the breakdown coefficient, which on the objects of development under consideration fluctuates in the range of 1.9 to 11.7. In general form a direct dependence of the breakdown on thickness is observed. Objects of development Samotlor (I, II and III) and Uzen' (I and II) have the largest breakdown and contain a large number of oil-bearing reservoirs and interstratifications. Thus, for example, their breakdown coefficients fluctuate in the range of 11.7 to 6.8. The maximum number of oil-bearing reservoirs in sections of wells of objects of development Samotlor and Uzen' reaches 15 to 25 as against 6 to 10 reservoirs in the objects of development of most other deposits. The objects of development of large deposits of Volgo-Ural'skaya Oblast are relatively less broken down.

The principal physicochemical properties of oils that affect the development of pools (the viscosity and temperature under reservoir conditions, the gas factor, the saturation pressure and the content of asphaltenes, tars and paraffin, etc) in producing reservoirs separated by small intervals of dense rocks differ insignificantly within most deposits. This contributed to the combination of several producing reservoirs and horizons into single large objects of development at the Arlanskoye, Uzen'skoye and Samotlorskoye deposits.

The differences in oil properties were one of the reasons for distinguishing independent objects of development only at the Shkapovskoye deposit. The viscosity of oil of the upper object, reservoir D_I of that deposit is 4 times greater, the oils are heavier, and the gas factor is one third as much as with oils of the lower object, reservoir D_{IV}. In addition, at the Mukhanovskoye deposit the pools of reservoirs D_I, D_{II}, D_{III} and D_{IV}, the oils of which also differ in their physicochemical properties, were included in a single object of development.

In examining the composition of oils attention is attracted by the relatively high content of asphaltenes and tars in oils of the Arlanskoye (22.4 percent) Uzen'skoye (17.7 percent), Shkapovskoye (reservoir D_I--14.9 percent) and Tuymazinskoye (13.2 percent) deposits.

The presented data indicate that some objects of development distinguished at the Uzen'skoye and Samotlorskoye deposits consist of very large objects in comparison with objects of development of the large deposits of Uralo-Povolzh'ye. Among the latter, objects of development of the Shkapovskoye (D_{IV} and D_I) and Tuymazinskoye (D_I) deposits are the smallest in thickness, in indicators of heterogeneity and in content of reserves per well and per unit of area. Those reservoirs are now entering a late stage of development. Many years of experience in operating them has proven to be highly profitable. The final oil yield for those objects with the existing development system reached 0.5-0.55.

The coefficient of oil yield is determined to a considerable degree by the coefficient of inclusion. Experience in the development of multireservoir deposits of Uralo-Povolzh'ye shows that when a large number of reservoirs are combined into a single object high inclusion is not successfully achieved over the thickness by flooding. Moreover, the process of flooding become difficult to control.

Due to the fact that the objects of development of the Uzen' (I and II) and Samotlor deposits are very stratified, it is advisable, evidently, to divide them into smaller objects in order to increase the completeness of the working of the oil reserves.

On the Arlanskaya area two objects of development have been distinguished: reservoir C-VI (confined to the lower part of the section, has larger thicknesses than other reservoirs, pools are of linearly extended form, a considerable portion of the reserves is confined to water-oil zones, etc); reservoirs C-VI^0, C-V, C-IV, C-IV^0, C-III, C-II and C-I are combined into a second object (the producing reservoirs have small thicknesses, except C-II, low values of permeability, and the zones of distirbution of traps in the plane do not coincide). Six large sections of development (I, II, III, IV, V and VI) were distinguished, three in the southern part of the area, where there are two objects in the section, and three in the north, where there is mainly an upper object.

On the Novokhazinskaya area, in contrast with the Arlanskaya, in the section of the terrigenous formation of the Lower Carboniferous there is a layer of limestone 4 m thick. All the producing reservoirs bedded below that limestone --a "boundary mark," have a single water-oil contact, and those bedded above--a layer of water-oil contact that extends for 20-25 m above in absolute position.

Combined into objects of development were reservoirs controlled by a single water-oil contact surface. The lower object includes reservoirs C-VI, C-VI^0, C-V and C-IV, and the upper consists of the single reservoir C-II, which in thickness and trap properties for the most part surpasses reservoir C-VI.

The distinguishment of producing members (objects) on the Novokhazinskaya area should be considered more successful than on the Arlanskaya. In the lower object in proportion to its flooding, work on the isolation of the lower reservoir is possible. After the lower object has been flooded the well can be transferred to the working of higher-bedded relatively impermeable reservoirs.

The Effective Disposition of Reserve Operating Wells

In planning the development of oil deposits, besides the basic number of operating and pressure wells, the drilling of a number of reserve wells is also envisaged. The drilling of those wells is an important technological measure to maintain the oil output and increase the oil yield, if in locating each well distinctive features of the structure of reservoirs on the given section and the state of their development are maximally taken into consideration.

On the Arlanskaya area according to the adopted alternative are arranged wells of the main group on a 600 x 800 m grid (separately for the lower and upper objects) and 500 x 600 m for the combined working of lower and upper objects. It was planned to develop the area with the support of stratal pressure through the introduction of extra-outline (mainly the lower object) and intra-outline (the upper object) flooding. The first series of operating wells on the lower object were planned to be at a distance of 1000 m from the pressure wells. Rows of operating wells of the upper object were placed between the rows of operating wells of the lower object.

On the Novokhazinskaya area according to the approved alternative of development (1962), separate working of objects of an independent well network with a density of 800 x 600 m per object taken separately was envisaged.

At the Nikolo-Berezovskaya area reservoir C-VI is mainly water-saturated, and all the above-lying producing reservoirs have lower trap properties and a higher degree of discontinuity than at the Arlanskaya. Therefore the system of arrangement of wells on a triangular grid with a distance of 700 m between the wells was used there (1964).

In the disposition of reserve wells at the Arlanskoye oil deposit, in view of the very complex geological structure, it proved necessary to apply multiple contraction of the grid (due to non-coincidence in the plane of zones of development of traps, the very complex position of the oil pool outlines of beds confined to individual reservoirs and layers, etc).

Reserve wells have been sunk: on sections with a high productivity of reservoirs (where the potentials are not being utilized because of limited productivity of existing deep-pumping equipment under a 127-mm operating column); in zones of high productivity of water-oil pools of reservoir C-VI where the above-lying reservoir C-II has not been drawn into active development (the combined working of both reservoirs on such sections is not rational due to flooding of reservoir C-VI, but simultaneous separate working of reservoirs C-II and C-VI is impossible due to an absence of reliable equipment); on sections where there proved to be an even number of rows of operating wells (2 or 4) in connection with the introduction of additional separate rows and foci in order to regulate the development of oil reserves and contract the oil pool outlines; in zones of the possible formation of oil pillars to determine the saturation in assumed eroded zones of producing reservoirs.

Reserve wells were arranged over the inner oil pool outline on an area with a total oil-saturated thickness of the trap of at least 3 m or in a water-oil zone with an oil-saturated thickness of at least 4 m. On the Novokhazinskaya and Arlanskaya areas the reserve wells were arranged in rows between drilled operating wells in such a way that the distance between the main operating and reserve wells proved to be 300 m, and the distances between rows to be 400 m (on an original grid of 600 x 800 m).

On the Nikolo-Berezovskaya area the wells were planned in parallel rows drawn through the bases, apices and centers of triangles formed by the grid of operating wells. The distances in the rows between wells and between rows were 350 m. On each well of the main grid there are three reserve wells. Thus the area with a well network in zones where reserve wells can be arranged (according to the above-presented conditions) was 12 ha on the Arlanskaya and Novokhazinskaya areas and 10.5 ha on the Nikolo-Berezovskaya.

Analysis of the geological field data showed that on the Novokhazinskaya area compaction of the network to 12 ha can be accomplished in practice on practically all sections except the marginal ones, where as a result of unfavorable lithological and structural conditions on separate zones the inclusion of reserves diminishes to 89-91 percent.

Due to the considerable heterogeneity of the structure of the oil pools of the Arlanskaya area the highest inclusion (73-96 percent) of the area of the compacted network is observed in its central part, where two objects of development are represented simultaneously in the section (sections II, III, V and VI) and the lowest (16-70 percent) on marginal sections. The inclusion of total oil reserves of all reservoirs of the compacting network on individual sections of the Arlanskaya area varies more than twofold (46-98 percent). However, analysis of the inclusion of oil-bearing areas and oil reserves by pools confined to individual producing reservoirs shows that on the Arlanskaya area, when reserve wells are arranged with observance of the described conditions, a relatively uniform inclusion of the compacting network of pools is achieved both as regards area (63-78 percent) and as regards oil reserves (63-72 percent). On the Arlanskaya area, with a compacted network of the disposition of wells as a function of the structural and lithological conditions the specific reserves per operating well for the pools of the main reservoirs (C-II and C-VI) differ by a factor of 2 or 3. However, on the same sections with regard to the sum of the reserves of all pools the values of the individual reserves differ by not more than 15 percent.

On the Nikolo-Berezovskaya area the reserve wells are arranged on two small sections where the zones of development of traps of the main producing reservoirs C-II and C-III coincide in the plane. On the whole the inclusion of the compacting network on the Berezovskaya area was 19 percent for the area and 28 percent for the balance reserves. Compaction of the wells network permits substantially increasing the inclusion of the producing formation of the development under conditions of joint development of different reservoirs.

A considerable increase in the yield of oil was obtained in 1969-1972 on account of the introduction of reserve wells into operation at the Arlanskoye oil deposit (Table 14).

Improvement of the Original System of Arrangement of Pressure Wells

The existing practice in planning the development assumes the selection of the main elements for maintenance of the stratal pressure as early as during compilation of the technological plan. In the selection of flooding, the principles of the arrangement and the location and number of pressure wells, the volume of water pumped and the pumping pressure are determined in the first planning documents. The optimum variant of the flooding system is substantiated by data obtained in hydrodynamic and economic calculations made for models of pools. After approval that variant is used in practice.

Due to the fact that real conditions of development and the structure of the reservoirs are far more complex than is assumed in the model, during the introduction of technological processes appears a non-correspondence of the adopted conditions of development to distinctive features of the pool structure or the obtained technological and economic indicators. A need arises to modify the adopted flooding system.

Table 14. Effectiveness of drilling of reserve wells

Годы разработки 1	Количество резервных скважин, находящихся в эксплуатации, % от всего фонда по площадям 2		Добыча нефти резервного фонда, % от добычи по площадям 3	
	Арланская 4	Новохазинская 5	Арланская 4	Новохазинская 5
1969	3	6,3	2,0	2,9
1970	6,3	15,2	7,5	13,4
1971	10,2	22,6	13,8	23,4
1972	16,5	27,9	23,5	27,3

Key: 1 -- Years of development
2 -- Number of reserve wells in operation, percent of total number of wells by areas
3 -- Yield of oil of reserve wells, percent of yield by areas
4 -- Arlanskaya
5 -- Novokhazinskaya

Table 15. Presence of traps in operating and pressure wells

Показатели 1	2 Эксплуатационный ряд скважин к западу от разрезающего нагнетательного ряда	3 Разрезающий ряд нагнетательных скважин	4 Эксплуатационный ряд скважин к востоку от разрезающего ряда
5 Общее число скважин	41	36	41
6 Число скважин, в которых песчаники отсутствуют (%)	19 (46%)	7 (20%)	6 (15%)
7 Средняя мощность песчаников пласта C-II, м	4,3	4,0	6,0

Key: 1 -- Indicators
2 -- Operating row of wells west of dissecting pressure row
3 -- Dissecting row of pressure wells
4 -- Operating row of wells east of dissecting row
5 -- Total number of wells
6 -- Number of wells in which there are no sandstones, percent
7 -- Mean thickness of sandstones of reservoir C-II, m

Experience in the development of the Arlanskoye deposit is instructive in that respect. Adopted mainly as the general plan was internal flooding through pressure wells arranged in linear series along the long axis of the structure. The oil-bearing area of the deposit, 10 years after the start of operations, was cut up into several long bands with a width of 3 to 5 km. Detailed geological field analysis showed that a continuous front of pumping through series of pressure wells was not successfully formed. Due to complex facial-lithological conditions water was pumped through a portion of the pressure wells.

Thus, as regards reservoir C-VI, in the pressure wells several large foci outside the contours were distinguished that exert no influence on the pool because the region outside the contour proved to be in better facial conditions than the zone of the reservoir near the contour. With respect to reservoir C-II, in the pressure series the influence of pumping was noted only on the first series, in the best case on the second operating series. As regards the reservoirs of the middle member, it was established that either the wells of the main pressure series are arranged in zones of trap replacement or the middle member has been shifted in the nearest operating wells. When pumping is done in accordance with the samples the pumping outside the contours on reservoir C-VI on sections II and III was gradually halted, and on reservoir C-II and the intra-outline zone of reservoir C-VI an additional pressure series was introduced, and the wide introduction of focal flooding on the middle reservoirs was recommended. Later, in compiling the plan for the development of the Arlanskoye oil deposit, similar changes were introduced on a broader scale.

In the sections of many pressure wells the traps were replaced by dense rocks. For a trap thickness of less than 1.2-1.6 m at the attained pressures, they have practically no intake capacity.

In 214 reservoirs (24 percent of the total) water is not taken in at all. In 177 reservoirs (20 percent), not more than 50 m^3/day of water is pumped in. In 116 reservoirs (13 percent of the total) the water intake capacity is not more than 51-100 m^3/day. Thus in 507 reservoirs (57 percent of all discovered perforations) the intake capacity is zero or negligibly small.

As a result, continuous dissecting lines with a great length have not been successfully created at the deposit. The lines of pressuring consist of relatively short series of pressure wells (1 to 10 wells) on each reservoir within the limits of individual sections or facial-structural zones (Figures 24, 27-30, 58).

The main reason for such a phenomenon is that the degree of heterogeneous structure of traps of the Arlanskoye deposit is very high. This has been established from a large amount of additional information on the geological structure of the pools. The series of planned pressure wells proved to be in zones with little or no trap thickness. Individual pressure wells have revealed sandstones with good characteristics and intake capacity on the edges of lenses; pumping through them is done unilaterally from the direction of development of sandstones with better trap qualities. Many sandstone lenses are not included at all in the flooding (Figures 24, 29, 30). Thus, on one of the sections of the Novokhazinskaya area the dissecting series proved to be in the zone of smallest thicknesses and an absence of traps of reservoir C-II (in 48 percent of the wells) in comparison with neighboring series of operating wells (Table 15).

The heterogeneous structure of the section exerts a considerable influence on the effectiveness of the system of flooding by the dissecting series and in the case of a combination of two objects (that is, of two dissecting series) in a single series of pressure wells. Such a combination was widely carried out at the Arlanskoye deposit. In 204 pressure wells over 400 reservoirs were combined. Of them in 6 percent of the wells the intake capacity is zero, and a considerable portion of the reservoirs have a low intake capacity. In 52 percent of all wells only one reservoir works out of two perforated; in addition, 84 reservoirs (31 percent) are in wells where two working objects are noted and take up less than 100 m^3/day. Thus 83 percent of the wells are working on practically a single reservoir of some kind.

For the Arlanskoye deposit, which has great oil viscosity, breakdown and zonality of development of sandstones, the task of developing the intermediate reservoirs (C-I, C-III, C-IV, C-V and C-VI^0) is very urgent. Of 883 cases of the discovery of intermediate reservoirs in pressure wells, only 190 take up water (21.5 percent as against 51 percent in the main reservoirs). The percentage of wells with low intake capacity in intermediate reservoirs is still higher than in main reservoirs (with an intake capacity of less than 100 m^3/day--56 and 45 percent respectively).

Thus, in the arrangement of pressure wells in series confined to definite lines, under the conditions of the multireservoir, structurally very heterogeneous Arlanskoye oil deposit one notes: 1) an absence of a continuous front of pressure on individual reservoirs; 2) the arrangement of a considerable number of separate pressure wells in zones of relatively small thicknesses of sandstones or in zones of the replacement of traps; 3) an absence of the inclusion of flooding of separate lenses of sandstones; 4) an absence of the possibility of taking into account the structure of traps of all reservoirs during the combining of two objects (up to 6-8 reservoirs) into a single pressure well; 5) lagging in the creation of reserves from lenticular thin reservoirs.

To judge from experience in the development of the Arlanskoye deposit, linearly extended series of pressure wells should be used under conditions of broken down and zonally developed traps for separate reservoirs of sandstones that have considerable zones of development.

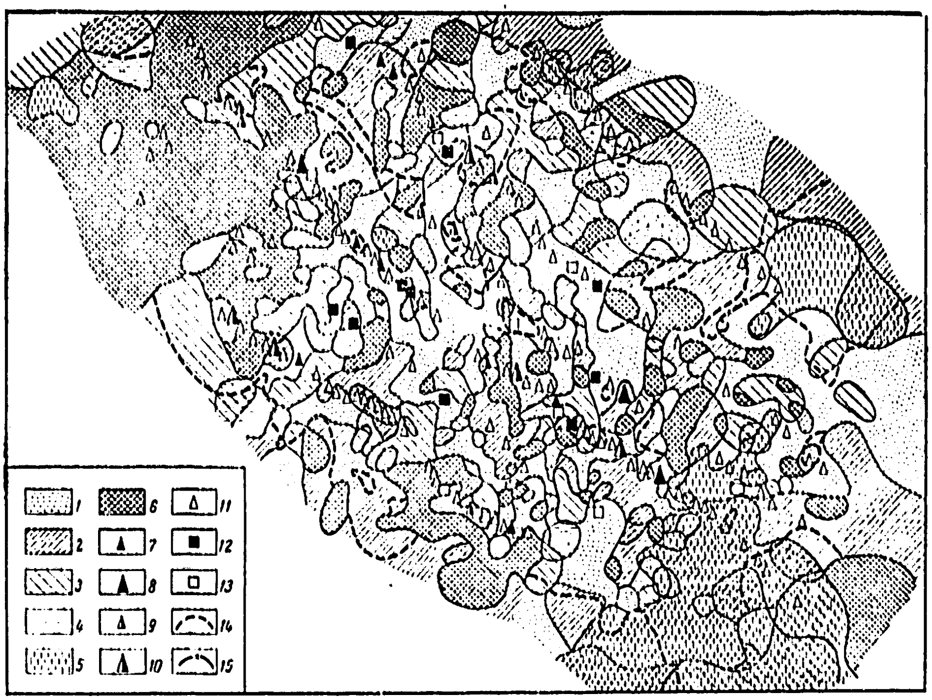

Figure 58. Diagram of the distribution of traps over reservoirs confined to the middle part of the section of the terrigenous formation of the Arlanskaya area.

1 -- sections where the areas of development of traps of reservoirs C-IV and C-V coincide in the plane;
2 -- sections of development of traps only of reservoir C-V;
3 -- ditto, only of reservoir C-IV;
4 -- ditto, of reservoir C-IV^0;
5 -- ditto, of reservoir C-VI^0;
6 -- sections completely without traps;
7 -- pressure wells where reservoir C-IV works according to RGD data;
8 -- ditto, for reservoir C-V;
9 -- pressure wells where reservoir C-IV does not work according to RGD data;
10 -- ditto, for reservoir C-V;
11 -- pressure wells of the Arlanskaya area;
12 -- pressure wells where reservoirs C-IV and C-V work simultaneously according to RGD data;
13 -- pressure wells where reservoirs C-IV and C-V do not work simultaneously according to RGD data;
14 -- summary outside oil pool outline of pools confined to the middle part of the section, drawn according to VPK position;
15 -- ditto, drawn along boundary of lithological replacement of rocks.

To increase the effectiveness of the flooding system at the Arlanskoye deposit it is necessary to stop pressurizing the water in individual wells of the series where a low intake capacity is noted (besides focal in zones with a small thickness of the sandstones). This permits increasing the volume of preventive work on lagging wells, increasing the pumping volume in them and improving the efficiency of the system as a whole.

Under conditions similar to the Arlanskoye deposit the use of selective flooding from the very start of development is very effective. It permits increasing the inclusions of reservoirs in the flooding, avoiding excess and ineffective pressure wells, assuring sufficiently high rates of oil extraction in the initial period, etc.

Under the conditions of mulitreservoir deposits during the combining of several reservoirs into a single object of development one of the main problems is very complete exhaustion of the oil from each reservor and each lens. It is necessary to strive to create independent networks of pressure wells and systems of effect (focal, dissection, etc) on each reservoir of the object. Economic calculations must be accompanied by careful consideration of the technological efficiency.

Obviously it is inadvisable at the start of development to rigidly determine the position of pressure wells. It is more advisable to select their location after drilling the basic group of wells.

Some Questions of Monitoring the Development of Deposits

In the development of deposits with the use of flooding methods the role of geophysical field methods of investigating wells grows. In the period of increase of the flooding of production and increase of the number of flooded wells, the main task of geological field investigations, side by side with estimation of the production of reservoirs, is the study and prediction of the paths for the movement of water through the reservoir to the bottom holes of operating wells.

At the present time radiometric methods (NGK, INK and INNK) are widely used to monitor the flooding of producing reservoirs and rise of the water-oil contact. The investigation and interpretation of the results of measurements are a complex task and require a creative approach to each specific case. The spatial distribution of thermal neutrons and gamma-radiation registered during radiometric investigations was caused both by moderating and diffusive neutron properties of the investigated medium. If the moderating neutron properties of the medium were caused by the hydrogen contained in it, the diffusion properties of the medium, which determine the ability of the medium to absorb and scatter thermal neutrons, depends on the content in the medium of elements with a large capture cross-section (chlorine, boron, etc). Such factors as the quality of the oil, the saline composition of the stratal water, the degree of saturation of the rocks with it and the lithological characteristics of the rocks influence in different ways the registered parameter.

To determine the oil and water saturation of traps in cased wells of the Arlanskoye deposit, the pulsed neutron-neutron method is widely used. Determination of the values of the parameter τ* as a function of the character of the saturation, obtained from data of measurements in intervals of perforated reservoirs known to be oil-saturated (262 measurements) and water-saturated (98 measurements), showed that the region of heterogeneous interpretation results from the influence of clayeyness, coalyness and compaction of traps and is in the range of values of 150 to 200 ms (Arbuzov, 1971).

In estimating the effectiveness of measurements in the intervals of reservoirs not revealed by perforation (680 measurements), the character of the trap saturation according to the pulsed neutron-neutron method was determined unequivocally in 61 percent of the cases. The reason for an equivocal interpretation in 18 percent of the cases was the lithological heterogeneity of the trap, which during the time of measurement was not successfully broken up in the part of the reservoir near the well. Analysis of the data characterizing the latter case (39 wells) showed that to obtain quality materials the interval of time between the casing of a well and the measurement must be at least 25 to 30 days.

The pulsed neutron-neutron method is also used to distinguish traps which were oil-bearing earlier and were later washed out by fresh pressurized water. The high chlorine content in the combined water in an oil-bearing reservoir, approximately equal to the chlorine content in stratal water, permits distinguishing unperforated intervals of the reservoir that have been washed with fresh water. The washing of sandy traps by highly mineralized stratal waters can be accompanied by increase of parameter τ by 10 to 15 percent. The registration of such changes is more reliable by the method of repeated measurements. It is based on the comparison of initially measured values of τ in a reservoir known to be oil-saturated with the indications of measurements after the assumed washing out with fresh water. Thus, according to measurements by the pulsed neutron-neutron method made in 1968 in well 4681 of the Novokhazinskaya area, the upper part of the trap in the range of 1276.8 t- 1279.5 m is characterized as oil-saturated, and the lower as saturated with stratal water. Two years later the pulsed neutron-neutron indications for that well rose not only against the earlier water-saturated part of the reservoir but also in the interval of the oil-saturated, which unequivocally indicates washing of the entire reservoir with fresh water. During testing a flow of fresh water with a small oil content was obtained from the investigated interval.

*The parameter τ is a value inverse to the decrement of thermal neutron damping.

The effectiveness of the pulsed neutron-neutron method in reservoirs completely revealed by perforation was evaluated from the data on 91 wells. Preliminarily, to determine the distorting influence of saline water filling a well, we examined 130 measurements in oil-bearing perforated reservoirs, the saturation of which was determined unequivocally from geological field data. In most of the examined cases within the limits of the oil-saturated trap an interval was noted that was characterized as water-saturated, which can be explained by the penetration of saline water from the well into the reservoir. Inconsiderable distortion of the trap saturation according to pulsed neutron-neutron data on account of penetration was noted only in rare cases. Of 91 examined wells (producing oil containing stratal water) the task of distinugishing a flooded reservoir from a number of perforated reservoirs was solved unequivocally only for eight wells. In that case only the source of flooding was established, since the boundaries of the flooding interval, as a rule, are distorted by the penetration of saline water from the borehole. This is the main reason for the low effectiveness of investigations of reservoirs completely revealed by perforation. In that case a considerable role is also played by long standing of the well before the measurement, the absence of reliable analyses of the water filling the well and insufficiently high quality of the measurements in isolated cases.

The results of reservoir investigations with water-oil contacts perforated in the roof were evaluated from data of measurements in 45 wells. Those reservoirs are marked according to pulsed neutron-neutron data by a sharp reduction of indications below the interval of perforation, and therefore a boundary which can be taken as the water-oil contact surface is not successfully distinguished in the unperforated part of the trap. On the basis of pulsed neutron-neutron indications it can be established that the unperforated part of the reservoir near the well in the interval from the lower unperforated opening to the initial water-oil contact is practically completely washed with saline water to a depth of at least 15-20 cm from the wall well. In the perforation interval the indications of the method are high, and the most probable explanation of low indications in the unperforated interval with consideration of the geological field data is vertical movement of the bottom water toward the low perforated openings. Analysis of 246 measurements of the group of cases under consideration permits the conclusion that the movement of water through the part of the reservoir near the well with a depth of at least 15-20 cm is widespread from the well wall on the Arlanskoye deposit during the working of traps with water-oil contact. This agrees with the conducted investigations of the possibility of forming flooding cones. Only for isolated wells, according to pulsed neutron-neutron indications, is it possible to distinguish the boundary of oil-saturation in a trap below the perforation interval. In such cases the water advances along dislocations between the column and wall of the well; this is accompanied by salination of the cement stone and can be established with the use of a neutron-gamma and a pulsed neutron-neutron complex.

During the working of reservoirs with water-oil contact, analysis of the geological field data usually permits establishing the cause of flooding. To confirm that and determine the path of water movement in the space beyond the pipe (along dislocations in the cement stone or over the unperforated part of the reservoir near the well) in a number of cases it is advisable to measure by the pulsed neutron method. The effectiveness of such investigations on the Arlanskoye deposit is about 60 percent for the conditions of an established well.

Widely distributed for estimating the character of the saturation of traps is a method based on determining the lifetime of thermal neutrons (τ). The possibility of distinguishing oil-bearing and water-bearing reservoirs by the lifetime of thermal neutrons results from the presence of a chloride content in the oil and water. The dependence of τ_{res} on the reservoir porosity, the mineralization of the stratal water and the chemical composition of the skeleton of the rock is used to calculate the coefficient of oil saturation from the lifetime of the termal neutrons (τ).

When there is a high and constant mineralization of stratal waters in a small range of variation of porosity over the section of a reservoir, the influence of the chemical composition of the rock skeleton is insignificant and the connection between the coefficient of saturation and the value of τ_{res} is expressed by the correlation $k_{sat} = a - \frac{b}{\tau_{res}}$, where a and b are constants determined by the porosity, the mineralization of the stratal waters and the influence of the rock skeleton.

As an example of quantitative estimation of oil saturation from the value of τ, data are presented on a well of the Arlanskoye deposit. Test well 2400, drilled in a flooded zone on the Ashitskiy section, revealed reservoir C-VI with a thickness of 6.8 m. According to pulsed neutron-neutron logging and induction logging the upper part of the reservoir (2.8 m) is saturated with oil and the lower (4 m) is flooded. On the differential curve the indications of the oil-bearing (200-355 ms) and flooded (122-200 ms) parts differ sharply.

Current water-oil contact in that well is noted at the absolute mark of -1169 m, and the reservoir bottom at -1173 m (the position of the initial water-oil contact is -1180 m). According to data of radiometric measurements (pulsed neutron-neutron logging), after drilling (August 1969) the residual oil saturation of the bottom part of the reservoir in well 2400 Ashit was 40-50 percent, which agrees with the geological field estimate obtained by other methods.

The possibilities of using the pulsed neutron-neutron logging method at the Arlanskoye deposit are limited because of the appearances of two flooding sources. Reservoir C-VI is flooded by stratal highly mineralized waters, and reservoir C-II by pumped fresh or waste waters.

In connection with the drilling of a large number of reserve wells at a number of deposits there also is the possibility of observing movement of the water-oil contact surface through the compilation of measurements of oil-water contacts from the data of wells drilled at different times. Those data are very reliable and precise on all sections where the reservoirs have a great thickness (5 m or more) and where oil is displaced by stratal water.

An example can be oil pools confined to sandy deposits of the Aleksinskiy horizon of the Nikolo-Berezovskaya area.

The oil pool of the Aleksinskiy horizon is confined to sandy deposits shielded by carbonate rocks. The sandy bodies represent closed reservoirs in which water-oil pools are developed (Figures 49, 50). The initial regime of the pools is elastic-closed and the pool is completely water-oil. The initial water-oil contact here has been registered at absolute marks of -1144.4 to -1145.4 m. Two wells drilled in 1972 have revealed water-oil contacts at absolute marks of -1143 and -1139.8 m. When the position of the water-oil contact in the newly drilled wells is taken into consideration, and its initial position in the nearest wells, washed thicknesses of traps in the pool of 0.6 to 4.6 m are obtained. In that stage of development the coefficient of oil yield for the pool is about 30 percent.

In the region of the Yuzhno-Nagayevskiy section a stratal vault pool of reservoir C-VI was put in operation in 1962. The oil-saturated thicknesses of the reservoir vary from 0.8 to 18 m. On the main portion of the pool reservoir C-VI has a relatively uniform structure and great thicknesses.

Two test (1958) and six operating wells (1960-1962) revealed a water-oil contact at absolute marks of -1178.2-1179.4 m. Well 1687, drilled in 1969 on the southwestern limb, according to electrometric data had a rise of the water-oil contact of 11 m, and well 1670, drilled at a distance of 200 m from the outer oil pool outline, a rise of 2.4 m. The large elevation of the water-oil contact of well 1687 in that region was caused by large takings of oil from adjacent operating wells. For well 2375, drilled in 1972 at a distance of 300 m from the outer oil pool outline, a rise of the water-oil contact of 2.4 m was noted. Thus on the described section a forcing of oil from the pool contour is observed.

If one takes into account the zonal development of the reservoir, the character of the flooding of wells where reservoir C-VI is perforated, the dimensions of the current water-oil contact according to pulsed neutron-neutron logging data in control wells (where reservoir C-VI is not perforated) and the change of the water-oil contact position according to electrometric data on wells drilled at different times, it is possible to estimate the pool production approximately.

It should be noted that the washed part of the reservoir, revealed by a number of newly drilled wells, has the same resistivities as the water-bearing reservoirs (ρ = 0.5 to 1.5 ohm•m). The coefficient of displacement at those resistivities is approximately 0.85 to 0.90, which agrees well with the results of laboratory determinations obtained from the displacement of liquid, performed by V. M. Berezin. For the permeability of 2.5 D of the sandstones of reservoir C-VI at the Arlanskoye deposit that coefficient is 0.85. In an estimate by the geological field method, on the whole for washed zones of reservoir C-VI on the described sections the coefficients of oil yield are 35 to 40 percent lower than with the coefficient of displacement obtained in the laboratory.

For analysis of the flooding of individual sections of the Arlanskoye deposit, which are in a long development, maps of the total takings of water (in operating) and the summary pumping (in pressure wells) have been compiled for a definite date.

With consideration of the facial characteristics and perforation of producing reservoirs, the uniting of one reservoir to another in the process of operation and analysis of the change of the outputs of oil and water in that case, with consideration of the qualitative RGD [expansion unknown] characteristics of pressure wells, and also analysis of waters taken in operating wells, with consideration of the character of the saturation of producing reservoirs in reserve wells drilled at different times, and other data, maps of the flooding of the main producing reservoirs have been constructed.

In zones where stratal, waste or fresh water has been introduced, several geological sections have been distinguished on each area. On those sections it has been established from RGD data in which reservoirs pumped water is being introduced and the balance oil reserves. The total accumulation of oil extraction (calculated on the date the flooding map is compiled) belongs in the balance reserves.

At the Arlanskaya area, in view of its complex geological structure, the "sections" distinguished in a zone of intensive flooding (within the limits of the Novonagayevskiy-Aktanyshbashevskiy sections of development) have different geological field characteristics: under large zones of dense rocks developed on reservoir C-VI, in the plane lie sandy-siltstone traps of reservoir C-II and, consequently, the operating wells take oil only from reservoir C-II.

In addition, the zones of replacement of traps breaks down the pool of reservoir C-VI into separate sections isolated from the influence of the main series of pressure wells, and they are in different conditions with respect to the effect of pumped water and the contour water of reservoir C-VI. In reservoir C-VI, according to our data, there are slightly flooded sections. There are two sources of flooding of wells on the given sections: the bottom and extra-outline waters of reservoir C-VI and the waters of oil field flows pumped into all the producing reservoirs. The obtained values of the current coefficients of oil yield vary on the distinguished geological sections of the Arlanskaya area by 3.7 times, on the Novokhazinskaya area by 2.6 times, on the Nikolo-Berezovskaya by 5 times, etc.

According to indirect data obtained as a result of the conducted investigations, a higher production of reservoirs is observed where they are developed separately.

When there is combined perforation of the producing reservoirs and a different effect on them (displacement by contour, bottom and pumped waters), the lower thin reservoirs, as a rule, have a higher percentage of flooding with less production (the Aktanyshbashevskiy section).

Thus on different sections of the Arlanskoye multireservoir oil deposit, which are in different geological and technological conditions (maintenance of pressure and method of operation), change of the coefficients of oil yield by a factor of 5 is observed.

The conducted analysis of flooding and the obtained values of the current coefficients of oil yield (although the latter also are approximate) permit recommending improvement of the flooding system and the application of various technological measures.

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